Third Annual
Western Provincial Conference
Rationalization of Water and Soil Research and Management

AGRICULTURAL LAND DRAINAGE

BRITISH COLUMBIA
ALBERTA
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MANITOBA
EDMONTON
SASKATOON
VANCOUVER
CALGARY
VICTORIA
REGINA
WINNIPEG

●hosted by the Province of Manitoba
Winnipeg, Manitoba
November 20 to 22, 1984

Proceedings

of

THIRD ANNUAL

WESTERN PROVINCIAL CONFERENCE

RATIONALIZATION OF WATER AND SOIL RESEARCH AND MANAGEMENT

"AGRICULTURAL LAND DRAINAGE"

Held at the
Fort Garry Hotel, Winnipeg, Manitoba
November 20 to November 22, 1984

Organizing Committee

Mindy Austford
Rick Bowering
Wayne Cowan
Crawford Jenkins
Hugh MacKay
Larry Whitney

Sponsored by the Government of Manitoba

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May 1985

Manitoba

INTRODUCTION TO PROCEEDINGS

On behalf of the Organizing Committee of the Third Annual Western Provincial Conference on the Rationalization of Water and Soil Research and Management, I take pleasure in providing these proceedings of the Agricultural Land Drainage Conference held at the Fort Garry Hotel in Winnipeg, November 19 to 22, 1984.

The Committee has asked me to thank the speakers for preparing and presenting relevant and interesting papers. The summary presentations and active participation by delegates during the final seminar brought the Conference to a successful conclusion. I enjoyed the welcome to "Winnerpeg" by Tom Weber, the interesting slide presentation on the Manitoba ARC Authority by Ian Dickson at the luncheon on November 20th and the speech stressing cooperation among all groups and individuals involved in water management by Nick Carter, Deputy Minister, Manitoba Natural Resources at the banquet on November 21st hosted by the Province of Manitoba. My thanks to all.

The 1984 Conference was a resounding success involving 218 delegates primarily from the prairie provinces but with registrants from St. Johns, Newfoundland to Vancouver, British Columbia and from Minnesota and North Dakota. Gook luck to the organizers of next year's conference in British Columbia.

On behalf of the Organizing Committee I also wish to thank the Local Arrangements Committee consisting of Rick Bowering (Chairman), Peter Blahut, Eric Blais, Rollie Fortin, Jamie Jewell, Gerry Kramer, Elsie Slimmon, Morley Smith and Dave Walker who left nothing to chance to keep the Conference running smoothly. We were pleased with the quality of the poster sessions put together in cooperation with the Local Arrangements Committee.

My sincere thanks to members of the Organizing Committee - Crawford Jenkins, Larry Whitney, Wayne Cowan, Hugh MacKay and Rick Bowering for developing a balanced program and persuading leading agronomists, engineers, economists and biologists in the water and soil research and management field to participate.

V. M. (Mindy) Austford
Chairman of the Organizing Committee

RATIONALIZATION OF WATER AND SOIL RESEARCH AND MANAGEMENT

PROCEEDINGS

TABLE OF CONTENTS

Page

Introduction to Proceedings iii

SESSION I - CONFERENCE OVERVIEW

Introduction 3
V. M. Austford
Chief of Hydrotechnical Services
Water Resources Branch
Department of Natural Resources
Winnipeg, Manitoba

Overview of Agricultural Drainage in British Columbia 5
R. A. Bertrand
Director, Soils Branch
B.C. Ministry of Agriculture and Food
Surrey, British Columbia

Overview of Agricultural Drainage and Current Policies of the Saskatchewan Water Corporation 17
Jerry F. Danyluk
Vice-President
Watershed Management
Saskatchewan Water Corporation
Regina, Saskatchewan

Overview of Legislative and Program Framework for Drainage in Alberta 25
D. A. Tupper
Head, Regional Services Branch
Water Resources Administration Division
Alberta Environment
Edmonton, Alberta

Agricultural Land Drainage in Manitoba 37
Thomas E. Weber
Director, Water Resources Branch
Department of Natural Resources
Winnipeg, Manitoba

Page

Agricultural Land Drainage - An Interprovincial Viewpoint 47
R. B. Godwin
Executive Director
Prairie Provinces Water Board
Regina, Saskatchewan

SESSION II - SOIL-WATER-PLANT RELATIONSHIPS

Subsurface Drainage in Alberta 53
B. A. Paterson
Head, Drainage Branch
Alberta Agriculture
Lethbridge, Alberta, and
N. E. Jensen
President, Jensen Engineering Ltd.
Olds, Alberta

Potential of Vertical Drainage for the Drainage of Prairie Potholes 81
F. Frank Penkava
Department of Agricultural Engineering
University of Manitoba
Winnipeg, Manitoba

Subsurface Drainage of Dryland Saline Seeps 85
Hank S. A. Vander Pluym
Soil Salinity Specialist, and
C. Livergood
Technologist
Conservation and Development Branch
Alberta Agriculture
Lethbridge, Alberta, and
L. Healy
Post Graduate Student
Farming For the Future
Agriculture Centre
Lethbridge, Alberta

Effect of Agricultural Land Drainage on Soil Characteristics and Crop Growth 105
R. A. Bertrand
M. G. Driehuyzen, and
D. Pedersen
Soils Branch
B.C. Ministry of Agriculture and Food
Surrey, British Columbia

Page

Agronomic Aspects of Peatland Drainage 125
Rouse S. Farnham
Professor, Soil Science Department
University of Minnesota
St. Paul, Minnesota

A Farmer's Viewpoint of Agricultural Land Drainage 149
Allan Chambers
Arnes, Manitoba

Transient Groundwater Flow Surrounding a Recharge Slough in a Till Plain 161
J. Gary Mills, and
M. A. Zwarich
Department of Soil Science
University of Manitoba
Winnipeg, Manitoba

Warmer and Drier than the Last 100 Years 191
H. M. Fraser
Regional Chief
Scientific Services, Central Region
Atmospheric Environment Service
Winnipeg, Manitoba

Hydrogeologic Studies for the Identification and Control of Detrimental Canal Seepage in Southern Alberta 205
Jock T. Forster
Soil and Drainage Agrologist
Earth Sciences Division (Soils Branch)
Alberta Environment
Lethbridge, Alberta

SESSION III - ENGINEERING AND ECONOMICS

Legislation and Policies Related to Agricultural Land Drainage in Saskatchewan 217
L. A. Gatin
Watershed Administration Manager
Saskatchewan Water Corporation
Regina, Saskatchewan

Page

History of Agricultural Land Drainage and Drainage Regulation in North Dakota 229
David A. Sprynczynatyk
Director of Engineering, and
Cary Backstrand
Chief, Regulatory Section
Engineering Division
North Dakota State Water Commission
Bismarck, North Dakota

Agricultural Land Drainage - A View from the Field 239
W. R. Poole
Manager, Turtle Mountain Conservation District
Deloraine, Manitoba

Engineering and Education for On-Farm Drainage in Manitoba 247
Brian English
Agricultural Engineer
Interlake Region
Department of Agriculture
Arborg, Manitoba, and
Neil MacAlpine
Farm Water Management Specialist
Soils and Crops Branch
Department of Agriculture
Winnipeg, Manitoba

The Economics of Drainage in Alberta 261
Ronald Desjardins
Resource Economist,
Kathleen MacDonald
Section Head, Resource Section, and
D. Wutzke
Research Assistant
Production and Resource Economics
Alberta Agriculture
Edmonton, Alberta

The Modification of Artesian Aquifers to Enhance Agricultural Drainage Systems 327
L. R. Gray
Head, Hydrogeology Section
Hydrotechnical Services
Water Resources Branch
Department of Natural Resources
Winnipeg, Manitoba

Page

Drainage Design Considerations for Fish Passage 347
Chris Katopodis
Arctic Resource Assessment Section
Freshwater Institute
Department of Fisheries and Oceans
Winnipeg, Manitoba

Design and Construction of the Namepi-Kennedy Drainage Project in Alberta 377
Dieter N. Lindner
Head, Hydraulics Section
Design and Construction Division
Alberta Environment
Edmonton, Alberta

SESSION IV - DRAINAGE IMPACTS

Prime Wetland Land Use Monitoring Activities and Needs in Southern Canada 405
Clayton D. A. Rubec, and
Paul C. Rump
Lands Directorate
Environment Canada
Ottawa, Ontario

Wetlands: Their Role in Prairie Water Flow Systems and Soil Development 431
A. Edward Osborne
Environmental Consultant
Moneneo Consultants Limited
Calgary, Alberta

Impact of Agricultural Drainage on Wildlife 451
R. K. Brace
Head, Migratory Birds Population Management
Canadian Wildlife Service
Saskatoon, Saskatchewan, and
G. W. Pepper
Saskatchewan Parks and Renewable Resources
Regina, Saskatchewan

Prairie Potholes and the Prairie Farmer 483
Jay A. Leitch
Department of Agricultural Economics
North Dakota Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota

Page

The Effects of Land Use Changes and Activities on Walleye Reproduction Success in the Valley River, Manitoba 495
Marc Gaboury
Fisheries Biologist
Fisheries Branch
Department of Natural Resources
Winnipeg, Manitoba

Make Your Wetland Work for You 511
Joseph P. Rossillon
President, Freshwater Foundation
Navarre, Minnesota

SESSION V - CONFERENCE SUMMARY AND RECOMMENDATIONS

Introduction 519
G. H. MacKay
Director of Manitoba Affairs
Prairie Farm Rehabilitation Administration (P.F.R.A.)
Winnipeg, Manitoba

Summary of Sessions on Soil-Water-Plant Relationships 523
John C. Hermans
Section Head
Conservation and Development Branch
Alberta Agriculture
Edmonton, Alberta

Summary of Sessions on Engineering and Economics 527
Derek Doyle
Assistant Deputy Minister
Department of Natural Resources
Winnipeg, Manitoba

Summary of Sessions on Drainage Impacts 535
R. W. Newbury
Research Scientist
Rivers and Streams
Freshwater Institute
Fisheries and Oceans Canada
Winnipeg, Manitoba

Reports from Working Groups 539

Page

POSTER SESSION PAPERS

Mole Drainage for Reclamation of Irrigated Saline Soil 553
T. G. Sommerfeldt, and
C. Chang
Research Scientists
Agriculture Canada Research Station
Lethbridge, Alberta

Salt Distribution in a Solonetizic Soil as Affected by Irrigation and Subsoiling 565
C. Chang, and
T. G. Sommerfeldt
Research Scientists
Agriculture Canada Research Station
Lethbridge, Alberta

Some Major Factors in Salinity Reclamation Rates 577
Ronald McMullin
Conservation and Development Branch
Alberta Agriculture
Lethbridge, Alberta

AGRICULTURAL LAND DRAINAGE CONFERENCE REGISTRATIONS 595

SESSION I

Conference Overview

Session Chairman: V. M. Austford

INTRODUCTION

by V. M. Austford

In April, 1981 the Premiers of the four western provinces met in Thompson, Manitoba and discussed, among other things, ways and means of promoting cooperation among the provinces. One of the recommendations emanating from that conference was that there be an annual conference on soil and water research and management hosted alternatively by the four provinces. The conferences were intended to promote a complete exchange of relevant information between provinces to enable each province to manage these vital resources in a more effective and efficient manner. The first conference on soil salinity was held in Lethbridge, Alberta on November 30 and December 1 and 2, 1982 with 240 people in attendance. The second conference on soil erosion and land degradation was held in Saskatoon, Saskatchewan on November 29 and 30 and December 1, 1983 with 225 attendees. In keeping with tradition, this conference on agricultural land drainage is being held the week after Grey Cup. At this time approximately 200 people are registered. A fourth conference on soil fertility is scheduled for British Columbia in 1985.

The conference has been arranged into five sessions: 1) Overview, 2) Soil-Water-Plant Relationships, 3) Engineering and Economics, 4) Drainage Impacts and 5) Summary and Recommendations.

To provide a focus for the conference, the Organizing Committee has prepared four questions for the summarizers to address on Thursday morning. These are:

"1. Do we know the effect, quantitatively, of excessive soil moistures on various crops?

2. Do we know enough of the physical parameters of soil moisture movement to design effective and efficient works to reduce excessive soil moisture?

3. What is required to enhance our ability to quantify the effects on the environment, in economic terms, of reducing excessive soil moisture by land drainage.

4. How can agricultural drainage be efficiently and effectively integrated with multiple use management of soil and water?"

These questions will be referred to by each session chairman.

The first presentation is entitled "Overview of Agricultural Drainage in Western Canada". It consists of five papers, one from each province and concludes with a comment on Interprovincial Aspects dealt with in the Prairie Provinces by the Prairie Provinces Water Board.

OVERVIEW OF AGRICULTURAL DRAINAGE
IN
BRITISH COLUMBIA

R.A. Bertrand[1]

1.0 INTRODUCTION

In British Columbia there are over 2 million hectares of land in the Gleysolic and Organic soil orders. Of these, approximately 600,000 hectares have at least some capability for agriculture that could be enhanced through control and removal of excess water (4). The great majority of the wetlands in B.C. are organic meadows in the Central Interior and Peace River regions of the province. Adverse climate restricts their use to producing native and cultivated forages.

The wetlands that are capable of producing a range of crops are located predominantly in the South Coastal region. Poorly drained lands of lesser significance are located in the Creston Valley, south of Kootenay Lake and in the North Okanagan and Salmon Arm areas of the Southern Interior region.

From an agricultural revenue point of view by far the most important poorly drained lands are those lying in the floodplain and the delta of the Fraser River. These lands comprise less than 3% of the Agricultural Land Reserves of B.C., but account for in the order of 30% of farm receipts in B.C. (7). The following graph illustrates the constraint that excess water is to agriculture on these lands. During the fall, winter, and spring precipitation greatly exceeds potential evapotranspiration, whereas

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1. B.C. Ministry of Agriculture and Food, Surrey, B.C.

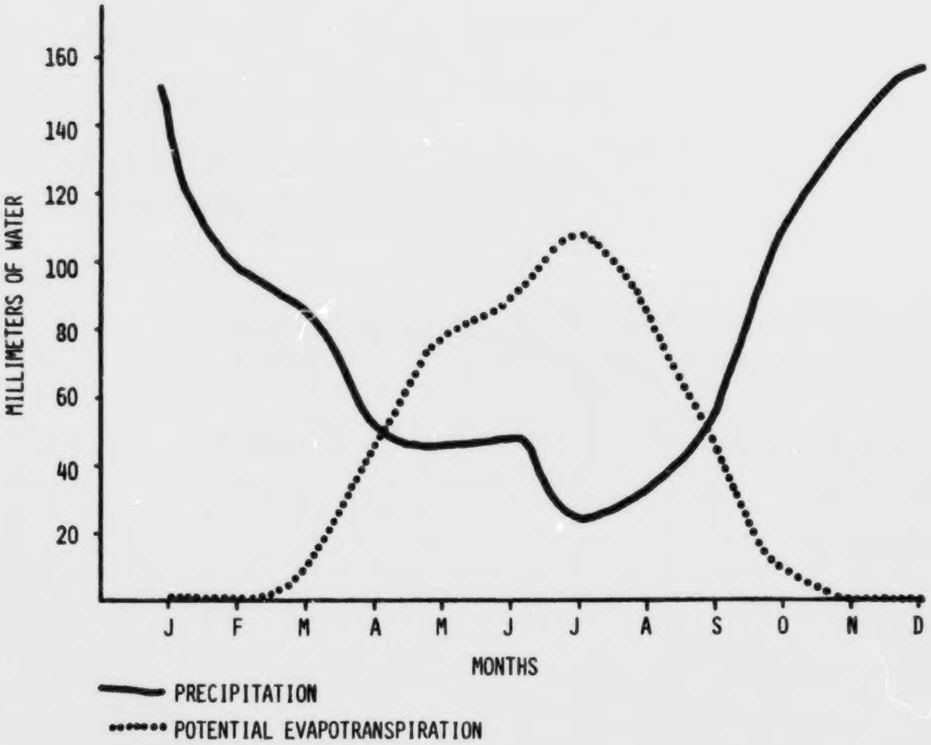

Figure 1: Average precipitation and potential evapotranspiration in the Fraser Valley.

during the growing season P.E.T. exceeds precipitation (1). It has often been said, and I believe this to be a fact, that excess water is the number one constraint to agriculture in the Fraser Valley.

2.0 HISTORY OF DYKING AND DRAINAGE IN B.C.

2.1 DYKING

The first systematic attempt at dyking was on Lulu Island (near Vancouver) in 1864. Following the pattern of settlement, dykes spread throughout the lower mainland and into the interior of the province. By 1953, dykes were protecting 79,000 hectares of land in the lower mainland, 8,100 hectares on the Kootenay River Flats at Creston, and 5,700 hectares at Pemberton in the Lillooet River Valley. In addition, there were some short sections of dyke scattered throughout the province for the protection of small areas of settlement.

These developments did not proceed without serious setback. In 1894, the highest flow since records have been kept occurred on the Fraser. The results of the flood were disastrous, and premier Davie, in a letter to Prime Minister Sir John Thompson, noted that "Bridges have been washed away, roads and trails obliterated, dyke walls broken down....What is plainly the lesson of the flood is the necessity of a comprehensive system of dyking which will include the whole inundated areas of the Fraser. The magnitude of the task places it beyond the ability of private enterprise and makes it clearly the duty of the State to undertake".

In 1948, the second highest flow on record occurred; and again the existing system was overwhelmed. There was no loss of life, but the damage was enormous. In June, near the peak of the growing season, 22,000 hectares of land were under water, 2000 homes were damaged, nearly 16,000 people were moved to temporary accommodation. The Trans Canada Highway and many secondary roads were inundated and damaged. The telephone and telegraph lines were cut. The C.N.R. and C.P.R. were both cut and Vancouver was without a Canadian rail link with Eastern Canada from May 28 to June 20. The direct cost for relief and rehabilitation was $17,500,000. This does not include the indirect cost due to the disruption of trade and communications (6).

At the present time, the dykes are being upgraded to a higher standard under a joint Federal-Provincial program to protect the Lower Fraser Valley against a repetition of the 1894 flood, or of the highest storm tides that have been recorded in the Straight of Georgia. When the program is completed most of the Lower Mainland will enjoy a high degree of protection against floods from external sources.

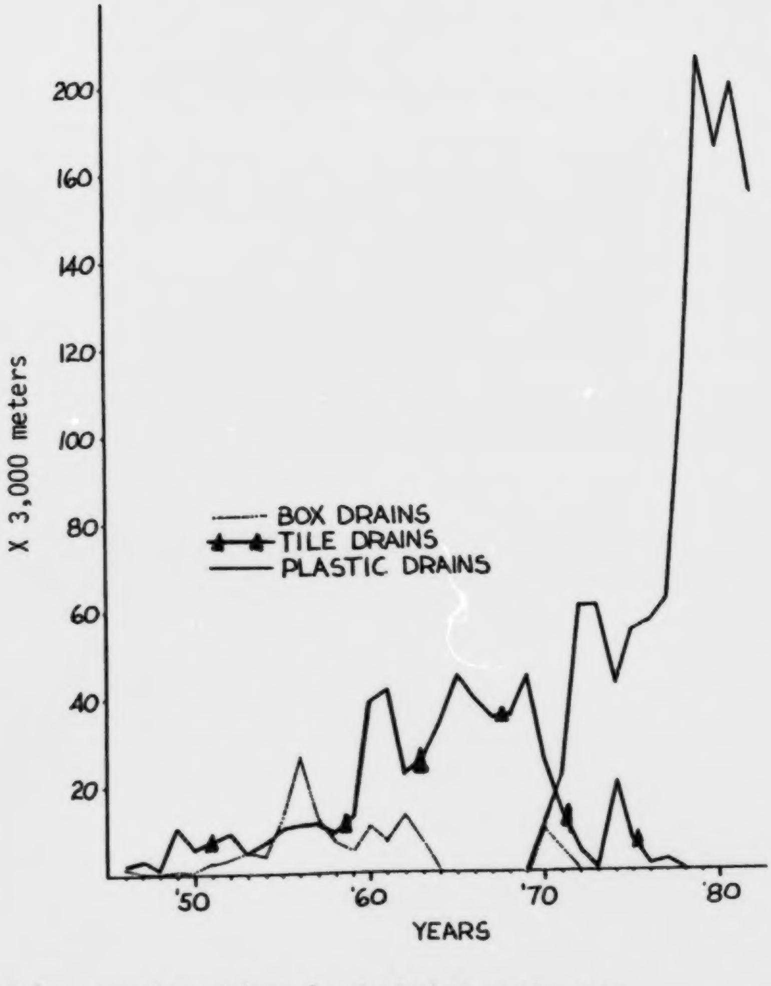

Figure 2: Drain construction in British Columbia.

2.2 DRAINAGE

The first attempts to remove excess water used open ditches at relatively narrow spacings. These, of course, were inconvenient to work around and occupied a great deal of land. To overcome the disadvantages of open ditches, cedar logs, which were in plentiful supply when the land was cleared, were placed across the open ditch and covered with soil. Later, rough cut cedar boards nailed together in an inverted V form were used extensively until the mid sixties when the cost of lumber became too high. Clay, foot-long, tiles were used for a number of years, and some systems are still functional to this day. These greatly improved the efficiency of drainage, but were costly to install and failure of the drain lines was a common occurrence.

In the 1970's perforated, continuous plastic tubing completely replaced clay tiles and is virtually the only material used today. This combined with high speed trenching equipment using laser grade control has greatly increased the use of subsurface drainage in B.C. Figure 2, illustrates the changes in drain construction and type of material used from the 1940's to the present.

3.0 CURRENT STATUS OF DRAINAGE ACTIVITIES IN B.C.

3.1 FRASER RIVER FLOOD CONTROL PROGRAM

In 1968, B.C. and the federal government entered into an agreement to contribute up to $36 million over a 10 year period for construction of flood control works in the Lower Fraser Valley. This agreement has been amended four times to increase the duration and funding levels. The expiry date will be December, 1985, and a total of $120 million will be expended.

It is estimated that a further $70 million is still required to complete construction and renovation of dykes along the Fraser River (2).

The $120 million will have been expended as follows:

- 50% for dykes designed to withstand the 1894 or 1948 flood plus 0.6 m of free board.
- 25% for internal drainage systems with the main expenditure being for large, regional pump stations.
- 25% for stream bank protection.

Approximately 63,000 ha of land (both agricultural and residential) in the Fraser Valley are protected from the Fraser River and the ocean. There are 330 km of dykes. Under the Fraser River Flood Control Program priority was given to protecting residential areas because of a higher benefit/cost than for protecting agricultural land. Therefore, when the current agreement expires, many rural areas will still have inadequate flood protection. Hopefully a new agreement can be entered into which will allow the entire dyking system to be completed (2).

3.2 REGIONAL DRAINAGE PROJECTS

In 1974, the governments of Canada and British Columbia signed a General Development Agreement (G.D.A.). As part of G.D.A., an Agricultural and Rural Development Subsidiary Agreement (A.R.D.S.A.) was signed in 1977. Under this agreement, which concluded in October, 1984, sixteen regional drainage projects were constructed which provided improved outlets for 12,000 hectares of poorly drained land (4).

Total expenditures were about $17 million, with $13 million being funded by A.R.D.S.A. and the remainder provided by individual land owners and local government.

In the Fraser Valley about 76,000 hectares are poorly to very poorly drained (3). From information on drain construction and area of land impacted by regional drainage schemes, it is estimated that about 30% of these poorly drained lands have been improved.

Currently negotiations are in progress to develop a new federal/provincial agricultural development agreement. A portion of the funds in the agreement will be used for additional regional drainage improvement projects.

3.3 ON-FARM DRAINAGE

As indicated in Figure 3, on-farm drainage installation is currently in the order of 500,000 meters per year. The provincial government provides assistance to land owners under the Agricultural Land Development Act. This program provides low interest loans (currently 6.25%) which are repaid over a maximum period of 15 years. Since its inception in 1966 the program has provided loans totalling $3,274,560. In recent years, over 85% of these funds have been expended in the South Coastal region. This has been a very successful program and funds are generally fully committed early in each fiscal year.

3.4 DRAINAGE CONTRACTORS

There are three contractors with modern equipment providing installation services to agricultural producers in B.C. Two have chain trenching equipment and one uses a drain plow. The recently concluded A.R.D.S.A. agreement provided funds totalling

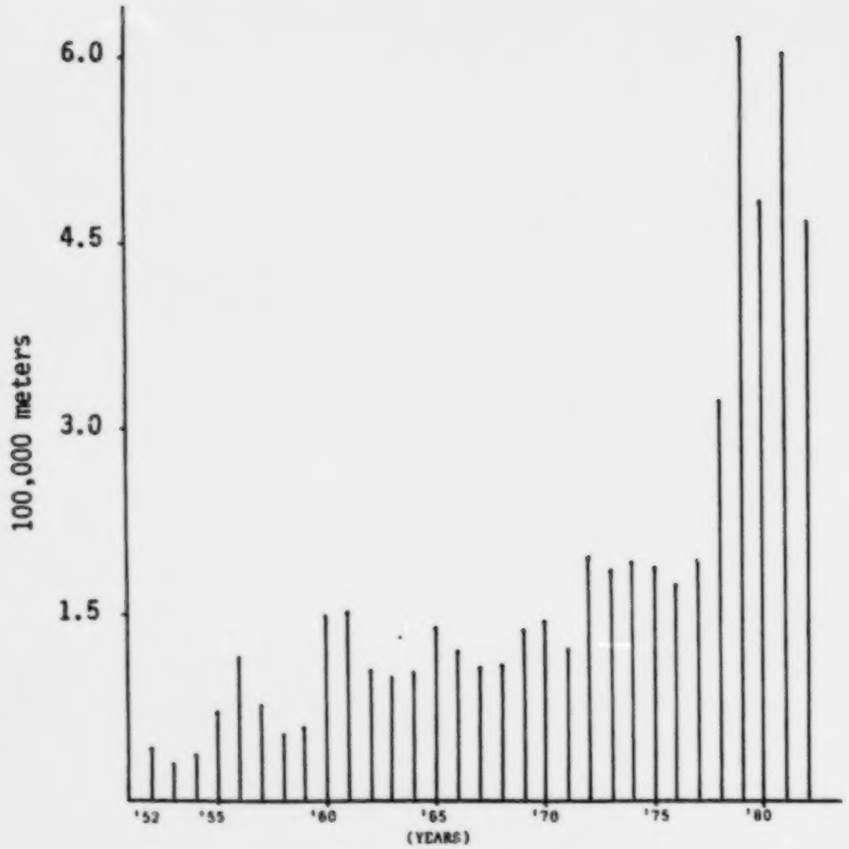

Figure 3: On-farm drain installation in British Columbia.

$120,000 to two contractors for assistance in purchasing trenching equipment.

3.5 INTERIOR WETLAND MEADOWS

The interior wetlands have historically been an important source of forage for the ranching industry. However, excess wetness results in low productivity of native sedges and very restricted access for grazing and harvesting. Various methods of improving these meadows have been investigated. If an outlet can be provided it has been found that subsurface drains at a relatively wide spacing (60 meters) provides excellent water table control. Drainage followed by establishment of a tame forage (reed canary grass) and fertilization has resulted in a large increase in the productive potential of these lands. Forty fold increase in yield have been measured (5).

4.0 PROBLEMS AND CONCERNS

4.1 SYSTEM MAINTENANCE

After installation, operation and maintenance of regional drainage and pumping systems is the responsibility of local government. This is a significant cost and municipalities vary widely in their commitment to ensuring that systems are maintained to a high standard. Vegetative growth in ditches is an on-going problem and cost and can have a profound affect on the efficiency of on-farm systems.

4.2 SUBSIDENCE OF ORGANIC SOILS

Drainage removes water from and introduces air into organic soils. In addition, cultivation breaks the soil into finer particles which increases the surface area exposed to air and soil microbes. As a result these soils subside. Some of the shallow organic soils of the Fraser Valley are disappearing and in some instances salinity and high clay content in the underlying mineral material is reducing the suitability of these soils for many crops. These soils have historically been used for intensive vegetable production and their loss is of concern.

4.3 OUTLETS

Regional systems have greatly increased the opportunity for many land owners to remove excess water from their land. However, where such systems are not in place many poorly drained soils do not have adequate outlets for drainage water. In some cases pumping or extensive excavations are required to provide an outlet. In some areas, this problem is exacerbated by increased runoff from adjacent hillsides which are in urban or industrial use.

4.4 ON-FARM DRAINS

Some problems arise from time to time with the proper functioning of the drain lines in on-farm systems. These include:

a) soil particles entering the drain line. In some soils, especially sandy soils, particles can be moved into drain lines if proper filter material is not used.

b) formation of iron ochre. Iron oxidizing bacteria form a gelatinous "iron ochre" material which can eventually clog drain lines.

c) over-tilling, double cropping and general intensive land use. These contribute to soil compaction which leads to surface ponding and poor performance of on-farm drainage systems.

REFERENCES

1. Coligado, M.C. 1983. The Climate of the Lower Fraser Valley. p. 86-91. In Soil Management Handbook for the Fraser Valley.

2. Fuller, D. 1984. Personal Communication. B.C. Ministry of Environment.

3. Sondheim, M., and H.A. Luttmerding. 1984. Soil Drainage Maps of the Lower Fraser Valley.

4. Talisman Land Resource Consultants. 1984. Draft report on Water Constraints Impacting Agricultural Development in British Columbia.

5. van Ryswyk, A.L. 1975. Capabilities and present land use for agriculture of interior wetlands. In Proceedings of Seminar on Interior and Coastal Wetlands of British Columbia.

6. Wilson, K.W. 1975. Some engineering and economic aspects of drainage. In Proceedings of Seminar on Interior and Coastal Wetlands of British Columbia.

7. ___________. 1978. British Columbia Agricultural Statistics Yearbook.

AGRICULTURAL LAND DRAINAGE CONFERENCE

November 20-22, 1984

Prepared by:
Jerry F. Danyluk
Vice-President
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Presented by:
Al M. Veroba
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A quote out of the Pearse Inquiry Participation Paper reads "like so many issues of public policy in Canada, water management must be geared to different problems in different regions". This statement is meant to have national scope; however, it holds very true for the Province of Saskatchewan. In spite of near record dry conditions in 1984, we in Saskatchewan could not underplay the importance of drainage and flood control. Heavy precipitation following spring break-up prevented many acres of cultivated land in North Eastern Saskatchewan from being seeded and a 7 inch rain in the South East corner of the province caused extensive damage to seeded crop in August.

Mindy Austford asked that my presentation provide a brief outline of legislation and policy aspects of agriculture drainage in Saskatchewan. The first topic on your agenda for tomorrow is a presentation of Saskatchewan Legislation and Policies by Lee Gatin. To avoid repeating ourselves, I will place emphasis on general overview of agricultural drainage and current policies of the newly formed Saskatchewan Water Corporation. Lee will direct his attention to legislation.

The quantity of water existing within regions of the province varies widely from year to year and within any given year. In general, North and Eastern portions of the province where population and industrial opportunities are more limited, frequently receive excessive precipitation resulting in flooding thus restricting the full development potential of the area.

During the past 14 years, there have been six major spring runoff events in the province. These were 1969, 1972, 1974, 1976, 1979, and 1982. All were directly a result of above normal soil moisture, snow packed conditions and spring precipitation. In the same time period, extensive damage occurred on seeded cropland following above normal summer rains on a more localized basis.

Flooding of agriculture land and urban property is a regularly recurring and increasingly more costly phenomenum associated with settlement and crop production on the prairies. Costs to the government and society due to flood damage are direct through payments of flood compensation and indirect as a result of crop losses due to land being taken out of production.

The total area of Saskatchewan is 161 million acres (65.15 M Hectares) of which 44.5 million acres (18.0 M Hectares) are developed for improved pasture, forage and crop production. According to the Canada Land Inventory Classification System, there are approximately 6 million acres (2.43 M Hectares) of class 5, sub-class W lands scattered throughout the class 1, 2, and 3 land areas. Much of the area classified as sub-class W has been downgraded to class 5 because of excess moisture. In other words, if the land was dewatered, it would fall into the class 1, 2, and 3 categories.

Saskatchewan farmers have always attempted to improve their net incomes by reducing direct operating costs and increasing their land base. They achieve both by land drainage and since 1949 the Saskatchewan Government has been assisting them.

I would like to briefly direct attention to the new course for water management which has been charted out by the Government of Saskatchewan. As of July 1, 1984, the Saskatchewan Water Corporation came into being. The new Water Corporation Act brought virtually all aspects of water under the control of the Corporation. The Corporation has been given the broad mandate to effectively and efficiently manage, administer, develop, control and protect the water and related land resources of Saskatchewan.

The primary responsibility of the Corporation is to deal with all surface and groundwater works, sewage works, and drainage works. A more controversial side of the Corporation is the power to amend and collect fees, levies, rates or charges for water usage.

Saskatchewan Water Corporation is comprised of four main divisions namely,

- Watershed Management
- Water Supply & Utility Management
- Resource Management
- Corporate Affairs

The Corporation's concept represents a new form of water resource management. Of primary importance to this concept, is the management, administration, development and control by watershed and the delivery of programs at the local level. This is achieved through the Watershed Management Division.

Six regional offices have been established and staff resources decentralized. The regional offices are designed as a one-stop water shop where a client can obtain approvals to construct surface and groundwater projects, obtain technical assistance, file complaints, and obtain information. Programs and policies of the Corporation will be delivered through the regional offices.

Water Supply & Utility Management Division will deal with municipal water supply and sewage effluent.

Technical and support services for the whole Corporation will be provided by the Resource Management Division. This unit will supply engineering services, hydrologic investigations and studies, forecasting and economic studies.

The Corporate Affairs Division will handle public affairs, administration and personnel, accounting and records.

The Corporation has only been functioning for four and one-half months. However, with the emphasis the Saskatchewan Government is placing on water management and water development, we are excited by the new concept and direction.

The Corporation is in the process of developing policies and programs to reflect the new mandate. But for now, we are administering the policies and programs which were transferred from the Departments of Agriculture, Environment and Urban Affairs. The four agricultural drainage policies I will outline include:

1) Water Control
2) Flood Control Policy for Urban Centres
3) Channel Clearing Policy for Rural Municipalities
4) Erosion Control

The Water Control Policy is designed to alleviate flooding and drainage problems associated with agricultural lands and to advance soil and water conservation through locally sponsored and co-ordinated programs. Engineering and technical services are provided without charge to groups of farmers who may be organized as conservation and development areas or watershed associations. Financial assistance is available only to these organized groups or local governments.

Financial assistance for project construction is provided on a cost-share basis. On projects which are strictly flood control and drainage, the Corporation pays two-thirds of construction costs, while the local community pays one-third. For backflood irrigation projects which are associated with flood control and drainage, 85% of the construction cost is paid by the Corporation.

This program has been well received over the years however we have reached a point on approximately 5 major drainage basins where the capacity of the major outlet is insufficient to handle any increased flows. Therefore, organized drainage development is being restricted until mitigative measures can be taken to alleviate downstream flooding. This may necessitate development of massive downstream engineering works to prevent flood damage or alternatively if the areas affected are insignificant in size, a flood prone land purchase program may be considered. The Water Corporation is reviewing the total water control program and we expect to announce policy changes by next spring.

The Flood Control Policy for Urban Centres is designed to assist cities, towns, villages or hamlets to alleviate flooding caused by flood waters entering from outside the limits and passing through the urban centre. Again, Saskachewan Water Corporation provides engineering and technical services at no charge to the urban centres; however, contribution of flow from the rural portion of the drainage area must be the major flooding factor. Construction assistance is provided on a cost-shared basis and includes:

- basic assistance for all projects - 50%;
- basic assistance is increased using a ratio of rural drainage area to the total area contributing;
- the last portion of the assistance formula is related to population size.

To ensure that the works are properly maintained following construction, up to two-thirds of the cost of maintenance work carried out by the municipality is paid by the Water Corporation.

The Channel Clearing Policy for Rural Municipalities was designed to assist rural municipalities who wish to undertake natural channel clearing and obstruction removal or maintenance of existing drainage ditches which were the responsibility of the municipality in the first place. Many of the creeks and channels throughout the province are obstructed by trees, brush and deadfall and other obstructions which cause flooding and erosion problems through roads and adjacent lands.

Financial assistance provided is two-thirds of project cost.

Gully erosion and the loss of productive soil due to sheet and rill erosion is of increasing concerns to farmers and municipalities. Silt from such erosion creates problems in downstream waterways, storages and structures. Gullies destroy and sever productive land and often threaten municipal roads.

Saskatchewan Water Corporation provides assistance under the Erosion Control Program to individual and groups of landowners, municipal and watershed authorities.

Again engineering and technical assistance are provided without charge and two-thirds of the cost of works constructed are paid by the Corporation.

All the programs are well received and are limited only by the staff resources to be able to handle them and the financing provided by the government.

We have a small supply of policies which I have just outlined on the table at the back. What I have provided is just a thumbnail sketch of each of those policies. Should there be any questions I will be pleased to attempt to answer them.

Thank you.

OVERVIEW OF LEGISLATIVE AND PROGRAM FRAMEWORK FOR DRAINAGE IN ALBERTA

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INTRODUCTION

Alberta Environment receives its mandate to manage the province's water resources from several pieces of legislation, including the Water Resources Act, the Drainage Districts Act, the Clean Water Act and the Department of the Environment Act. Of these, the Water Resources Act and the Drainage Districts Act are, to date, the most relevant to agricultural drainage.

In Alberta, water is managed in accordance with the overall economic and social objectives of the province. Overriding considerations relate to the government's commitment to maintaining balanced economic growth, the general welfare of Albertans, and the present and future quality of life. Principles of water management as they relate to drainage include:

1) Encourage multi-purpose projects versus single purpose.

2) The responsibility for initiating a water management project involving drainage should usually lie with the local government or the individual.

3) Permanent water bodies should be protected from indiscriminate drainage.

4) The environment and land owners should be protected from indiscriminate drainage by other landowners.

The mandate for drainage is derived primarily from the Water Resources Act and from the Drainage Districts Act. All authority for diversions, including drainage, derives from the Water Resources Act which is the basis for the government's regulatory rule. The Drainage Districts Act is restricted in application to the nine existing drainage districts, but it allows the formation of additional districts. The principal program mandate for drainage is Position Paper No. 5, a government policy paper entitled "Cost-Sharing for Water Resource Management Projects".

THE WATER RESOURCES ACT

The underlying objective of the Water Resources Act is to foster the orderly development and long-term management of the province's water resources. It does this by:

1) Vesting in the province ownership of all water.

2) Including all water within the jurisdiction of the Act.

3) Requiring an approval under the Act to drain water or to otherwise alter its natural course.

4) Requiring a permit for all activities involving construction capable of interfering with the present or future development conservation or management of water.

The definition of water under the Act is "Water means all water on or under the surface of the ground". For purposes of the Act, this has eliminated the complex common law concepts relating to casual water and surface water, although in suit between individuals, these concepts may remain. This broad power of the Water Resources Act allows for better management of drainage activities because it requires downstream landowners to accept natural drainage from higher land where this drainage has not been altered in any way. Under the Act, drainage projects must be licenced and they can be implemented when appropriate easements have been obtained.

Section 5 of the Water Resources Act provides the general prohibitions of the Act. With respect to agricultural drainage, it prohibits any activity involving the diversion or use of water without authorization under the Act. Where works have been carried out without proper authorization under the Act, Section 73 (4) provides the Minister with authority to order any person to remove, breach, destroy or otherwise render ineffective these works. Further, where necessary, Section 6 of the Act allows the Minister to authorize anyone to enter private lands to remove or otherwise render ineffective any works constructed without authority under the Act. These various sections have been utilized to correct problems, generally between landowners, wherein one landowner has undertaken a water management activity, such as drainage or storage, to the detriment of the other.

THE DRAINAGE DISTRICTS ACT

The Drainage Districts Act provides a mechanism whereby a group of landowners can band together for the common "good" to undertake drainage of lands affected by excess water. A drainage district is essentially a local government whose sole purpose is the construction and maintenance of community drainage ditches within the established boundaries of the district. These districts exist within other local governments such as counties and may cross boundaries to include more than one local government.

The locations of the nine drainage districts are shown in Figure 1. The first drainage district was created over 70 years ago and the most recent was created in the late 1950's. The districts are formed and operated entirely by the landowners within the district. The board of trustees of each district can pass bylaws and regulations, levy a drainage benefit tax against lands in the district and enter upon such lands as required for the construction of works. Drainage districts are eligible for assistance under the department's water resources grant program.

PROGRAMS RELEVANT TO DRAINAGE

Provincial Projects

Provincial Projects are those projects fully funded and undertaken by the province. Ordinarily the province operates and maintains these projects although sometimes, by special agreement, the responsibility for operation and maintenance is transferred to the appropriate local authority. This latter type of provincial project is usually one providing the major outlet for drainage from a large portion of one or more local authorities. The Namepi-Kennedy project to be discussed later during this conference is this type of project.

Cost-Shared Projects - Position Paper No. 5

To encourage water management activities at the local government level, the province established Position Paper No. 5 which allows cost-sharing, generally 75-25%, between the province and local government, on eligible projects.

Among the types of water management projects eligible for funding under the Position Paper, are flood control and drainage. Projects are initiated by the appropriate local authority. Most often, one or more landowners will approach the local authority for assistance in resolving the water problem affecting them. This often includes a need to drain wet areas and provide some protection against frequent flooding. If the local authority supports the project, it will retain a consultant to identify the problem, examine alternative solutions, and make a recommendation. If, after this has been completed, the local authority wishes to proceed, it applies for cost-sharing.

Although many of the projects will include benefits to two or more landowners, the department will allow cost-sharing for projects involving one landowner provided that public benefits also accrue from the project.

Technical Assistance - The Farm Water Management Program

The department, under its Farm Water Management Program, also provides technical assistance to landowners wishing to implement a water management or drainage project. Under this program, the department will provide the required resources to investigate the problem, carry out any required surveys, provide a design for the proposed project, and assist the landowner by providing construction staking. The landowner is responsible for actual construction of the project.

DIRECT INVESTMENT IN DRAINAGE PROJECTS

Government investment in drainage projects has been significant over the years. Since 1981, projects qualifying under Position Paper No. 5 have totalled in the range of $3 to 6 million per year. As indicated previously, the Alberta Government funds 75% of these projects and the local authority funds 25%. 50 to 70 percent of these funds have been directed to projects having a drainage component.

Provincial Projects have accounted for 5 to 6 million dollars per year over the past few years. These expenditures are directed towards repair costs on older structures, implementation of erosion control projects, and implementation of flood control and drainage projects. The drainage/flood control component is difficult to separate but amounts to about $1/2 to 2 1/2 million annually. These costs do not include costs of research, government employee costs and related overheads.

TYPES AND LOCATION OF DRAINAGE

Open Drains

With the exception of drainage related to salinity control and irrigation activities, the majority of drainage projects utilizing drainage ditches appear to be located in the central and northwestern portion of the province.

In particular, the Grande Prairie/Peace River area, and the area from the Paddle River Project east to the Vermilion area and south to the Red Deer area appear to contain the bulk of the drainage projects.Most of these projects utilize surface ditches or open drains.

Open drains are attractive to landowners because of their ease of construction with readily available equipment and because they can usually handle larger volumes of runoff than tile drains.

Tile Drains

Historically, tile drains have not found widespread use in Alberta. Recently, however, aggressive marketing and some natural advantages have resulted in an increase in the amount of tile drainage being carried out in Alberta. To date, approximately 15 million lineal feet of tile drainage have been installed, draining up to 30,000 acres. The advantages of tile drainage, often offsetting the high initial cost, include low maintenance costs, an ability to farm over the tile, reduced erosion, and an ability to regulate the outflows. The long term impact of increased tile drainage, especially in salinity control, needs to be assessed.

Drainage for Salinity Control

The salinization of agricultural land is an item of grave concern to the province. It is currently estimated that some 1/2 million acres of agricultural land in the dryland area of Alberta are affected by salinity. Alberta Agriculture estimates that this figure is increasing by 10% per year. An additional 200,000 acres of salt damaged agricultural land exist in the irrigated areas.

Although the causes of salinization are only partially understood, much of it relates to groundwater movements and the geology of Alberta, which permits salts to percolate to the surface. This situation is occasionally related to seepage from irrigation ditches, but is more frequently related to the cropping techniques used and to the groundwater flow systems. Suggested control measures include the construction of surface drainage ditches or subsurface drainage systems.

A variety of research programs are ongoing and some progress is being made, however, a comprehensive salinity control program would be required to halt or reverse the current destructive progression of salinization in Alberta.

FLOOD CONTROL VERSUS DRAINAGE

An additional and perhaps self-evident aspect of flood control/drainage is that many projects constructed to provide some degree of flood protection also serve to remove excess waters from the land more quickly than was the case prior to the project. This may be more quickly than is necessary in relation to the needs of the crops involved. Thus, while providing flood control benefits, the project will also provide drainage benefits. For this reason, the objectives of drainage and flood control have usually been attacked under the same heading and using the same funds.

In the past two years, further consideration of these two subjects has shown that many landowners expect to have water on their lands for a short time during the spring and following heavy rains, and it is only when this water is not removed from their land within a certain time that they become concerned or are adversely affected. It is possible, therefore, that drainage ditches need not be designed for the occasional heavy flooding which might occur, but more specifically could be designed to assist in the removal of the water which is in excess of requirements.

This situation, accompanied by the fact that flood control projects are generally very costly has prompted the department to review the need for a separate policy on agricultural drainage as opposed to flood control. A few projects recently proposed by local authorities have, in fact, identified as the primary objective a need to remove flood waters within a specific number of days. These projects have received departmental approval.

Extent of Drainage

There are no data readily available to permit an accurate estimate of the amount of drainage that has taken place over the years.

In addition to the problem of distinguishing between drainage and flood control, any determination of the amount of drainage that has occurred is complicated by the fact that other provincial agencies such as Agriculture, Transportation, and local governments are also occasionally involved in drainage. Some illegal drainage has also occurred and this often goes undetected unless the department receives a complaint related to the impact of that drainage.

CURRENT DIRECTIONS

Integrated Resource Planning

Alberta is one of the very few places left still opening new lands for agricultural production. In support of this activity, the Department of Energy and Natural Resources has divided the province into three zones (Figure 2), the White Zone comprising the existing patented lands, the Yellow Zone containing those Crown lands that are being considered for or are available for conversion to agricultural production, and the Green Zone containing lands that are being managed for non agricultural uses. That department has developed integrated resource planning committees comprised of representatives from appropriate departments such as Environment, Agriculture, Transportation, and Municipal Affairs. This allows the identification of those lands that can best be opened for agriculture and those that should be withheld from agriculture. In many cases, where land has been identified as being of low agriculture capability, poor drainage is the critical factor; improved drainage would increase the agricultural capability.

This integrated planning approach allows important drainage courses to be withheld from title or to be caveated by easement on titles, so that the drainage infrastructure required for agriculture can be developed without a later requirement to recover the necessary lands from private title.

Agricultural Land Base Study

The Alberta Government is currently in the midst of a major agricultural land base study. The goals of this study are to:

1) increase the contribution of the renewable resource sector to the provincial economy,

2) to increase the rate of rural economic development and

3) to decentralize economic development activity to all regions of the province.

Within the framework of this overall study, the province is carrying out a major inventory of Alberta's drainage requirements. This inventory is funded primarily by the Water Resources Commission with input from Alberta Environment and Alberta Agriculture. The study began in September, 1983 and will be completed by September, 1985 at a cost of $850,000.

This drainage inventory study is a three part study. The first part is to identify a method which will produce a reliable inventory; the second is to conduct an inventory of the drainable lands in the White and Yellow zones of the province; the third is to determine the net drainability of the lands identified in the inventory. The drainability assessment will be based on factors such as economics, productivity, downstream hydrology, and environmental effects.

The first part of the study has been completed. Color infrared photography at a scale of 1:50,000 was selected as the method for collecting the information for the inventory. A stratified sample of the White and Yellow zones was flown producing stereo photographs of 340 townships.

The second phase of the study, producing the inventory, is underway. Of the 340 townships photographed, 130 will be interpreted by trained personnel to determine and classify all of the wet lands. This information will than be entered into a computerized data base so it can be retrieved as either maps or surface area and classification data, or both, for any section inventoried. This stratified inventory will than be statistically extrapolated on a regional basis for the White and Yellow zones of the province.

The third phase, that of assessing the potential drainability, is more complex. Since neither funding nor time permit a detailed complete inventory but only a statistical sample, the drainability assessment must also be a sample. The factors which have been identified as influencing the drainability are: benefits of increased agricultural production, costs of drainage both on and off farm, downstream hydrologic and hydraulic impacts and the costs to mitigate them, and costs of mitigating habitat loss to wildlife and fisheries.

This type of analysis requires relatively detailed input figures to be meaningful. For this reason, an approach has been chosen which will involve analysis of several small basins (10 townships or less) which are representative of different areas and drainage concerns throughout the province. The entire study is being directed by an interdepartmental committee with representation from Alberta Environment's Planning Division, Alberta Agriculture's Land Use and Drainage Branches, and Alberta Energy and Natural Resources' Fish and Wildlife Division.

The results of the drainage inventory study will undoubtedly have a direct bearing on policies and programs directed at enhancing Alberta's agricultural land base. The methodology developed during the study should be transferable and therefore may be of interest and value to other resource agencies, particularly those in Saskatchewan and Manitoba.

River Basin Planning

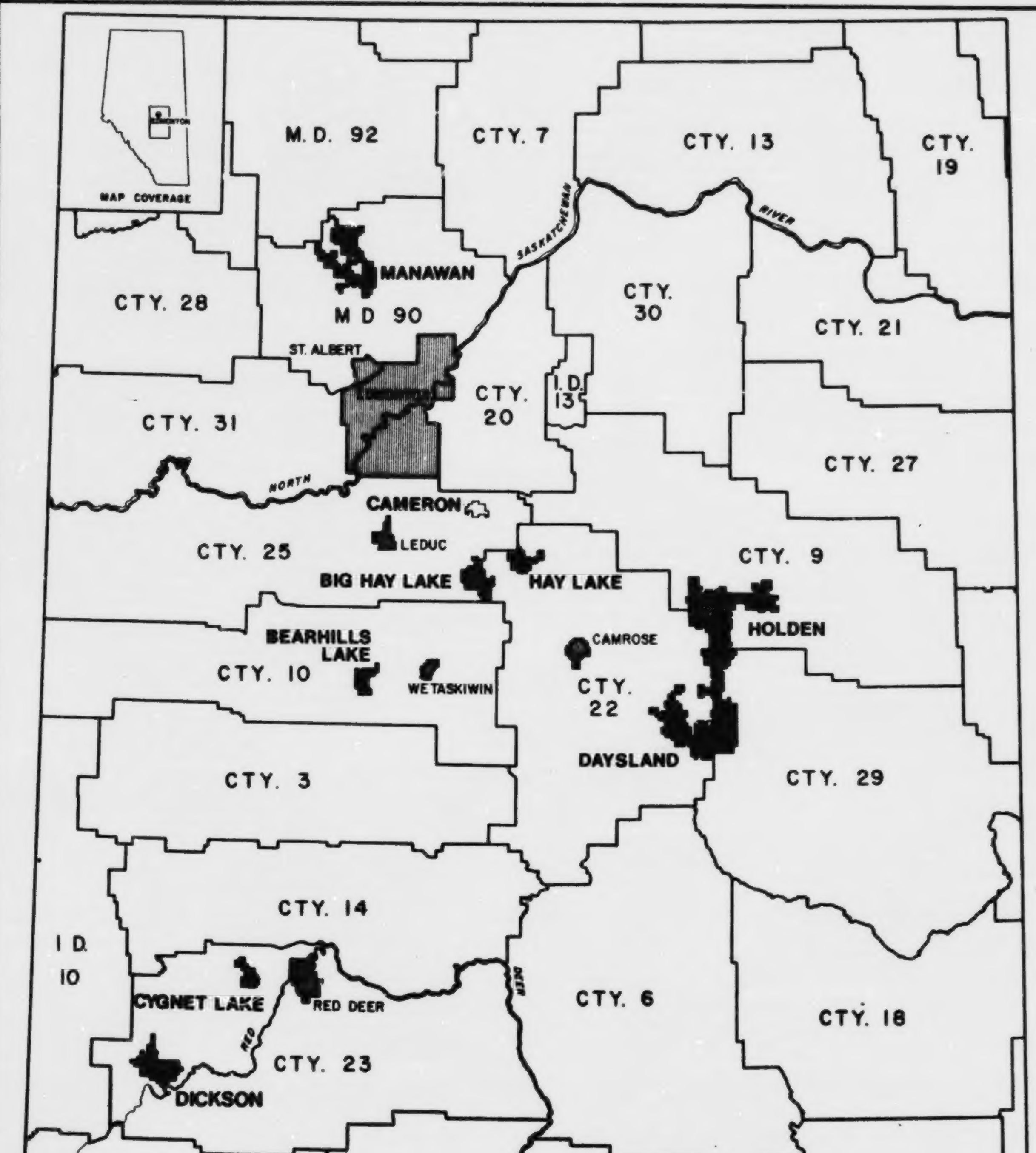
The province has, for some time, been carrying out the planning necessary for effective water resource development and management. This planning is done on a river basin basis, with the most notable current activity being the South Saskatchewan River Basin Planning Program. Included in these studies is consideration of a wide range of resource management factors including water use and demand, and drainage needs. The province considers these planning studies essential to the efficient, economical, and orderly development of its water resources.

CONCLUSIONS

Alberta has an active and broad approach to agricultural drainage and this approach enjoys strong political support. The necessary legislation is in place to ensure that drainage activities are carried out in support of provincial resource management objectives. Further, Alberta has been innovative in its efforts to solve existing problems and prevent future problems from new drainage projects, and it has been endeavouring to put suitable drainage plans in place prior to the opening of new lands.

ACKNOWLEDGEMENTS

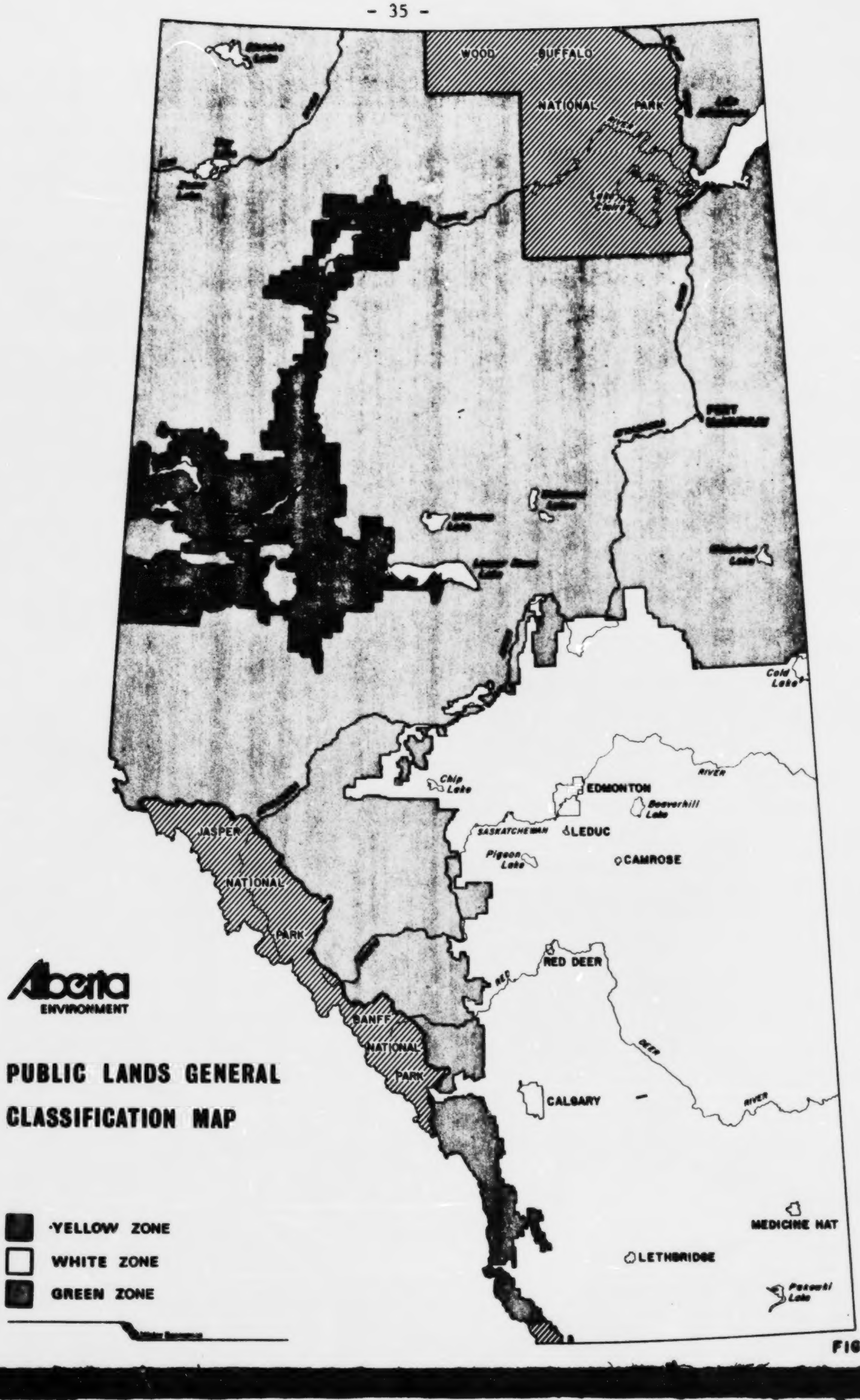
Mr. Carl Surrendi and Bruce Maclock of the department's Water Resources Planning Division provided substantial assistance in preparing this paper. This is gratefully acknowledged.


MAP COVERAGE
M.D. 92
CTY. 7
CTY. 13
CTY. 19
SASKATCHEWAN
RIVER
MANAWAN
CTY. 28
M D 90
CTY. 30
CTY. 21
ST. ALBERT
CTY. 20
I.D. 13
CTY. 31
CTY. 27
NORTH
CAMERON
LEDUC
CTY. 25
CTY. 9
BIG HAY LAKE
HAY LAKE
HOLDEN
BEARHILLS LAKE
CAMROSE
CTY. 10
WETASKIWIN
CTY. 22
DAYSLAND
CTY. 3
CTY. 29
CTY. 14
I D. 10
DEER
CTY. 6
CYGNET LAKE
RED DEER
CTY. 18
RED
CTY. 23
DICKSON
RIVER
CTY. 17
M. D. 48
M. D. 47
SPECIAL AREA 2
LEGEND:
HAY LAKE DRAINAGE DISTRICT

Alberta
ENVIRONMENT

DRAINAGE· DISTRICTS (1984)

FIGURE 1


WOOD BUFFALO NATIONAL PARK
RIVER
Lake Claire
FORT McMURRAY
Lesser Slave Lake
Cold Lake
Chip Lake
EDMONTON
RIVER
Beaverhill Lake
SASKATCHEWAN
LEDUC
Pigeon Lake
CAMROSE
JASPER NATIONAL PARK
RED DEER
RED
DEER
RIVER
BANFF NATIONAL PARK
CALGARY
MEDICINE HAT
LETHBRIDGE
Pakowki Lake
Alberta
ENVIRONMENT
YELLOW ZONE
WHITE ZONE
GREEN ZONE

PUBLIC LANDS GENERAL CLASSIFICATION MAP

FIGURE 2

AGRICULTURAL LAND DRAINAGE IN MANITOBA

BY

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PROVINCE OF MANITOBA

A PAPER PRESENTED TO
AGRICULTURAL LAND DRAINAGE CONFERENCE
WINNIPEG, MANITOBA
NOVEMBER 22 to 22, 1984

AGRICULTURAL LAND DRAINAGE IN MANITOBA

Manitoba at the lower end of the major drainage systems of the prairies was discovered and settled by dependence on water transportation. The early agriculture development occurred on the productive land adjacent to the waterways in the lowlands of the Province. The residual fine, textured soils, from Lake Agassiz deposits, provided excellent soils for the production of good quality grains.

The existence of natural levees along the rivers which were built by the depositing of silt during periods of flooding from the channels, prevented the natural drainage into rivers. These conditions led to the formation of large swamps covered with peat where the run-off from the upper part of the watershed was trapped in the low areas in the valley. These areas prevented the expansion of agriculture. As the demands for land increased, the Dominion Government granted swamp land areas to the Province on the condition that sufficient drainage be undertaken to render the land arable. There are records that indicate as early as 1883 some areas were reclaimed in this manner.

The coming of the railways in the latter part of the 19th century, brought a quick, efficient outlet for agricultural production from the Province which found a demand in the United States and eastern Canada. As these markets and settlement grew with the advancement of the rail lines through the Province, demands for agricultural land increased.

Twenty-five years after the Province was established, the government realized that the reclamation of the swamp lands lying between the escarpment and the Red River, Lake Manitoba and Lake Winnipegosis, was justified and necessary. It was recognized that the lands would eventually add financial stability to the provincial economy, but the local municipalities of the day were not large enough or financially able to undertake the required works. The government in 1895 passed the Land Drainage Act which provided the framework for implementation of large scale organized drainage in the Province.

The procedures under the Act required that a petition requesting the formation of a District from the majority of the landowners in an area was the initial step, followed by an engineering report setting out the area to be benefitted with an estimated cost of the works. This report along with the Minister's recommendation was submitted to Cabinet and if approved, a District would be formed by Order-in-Council.

Once the District was formed, the Act required that funds for construction would be raised by the sale of debentures through the Province with or without the guarantee of the Province. In any case, the lands within the District were subject to a first lien in favour of the Provincial Treasurer for payment of all assessment for interest and debenture funds. The Act, however, was silent on the provision of procedures and responsibility for maintenance which became a major issue during the 1930's.

During the period 1895 - 1929, 24 Districts were organized throughout the lowlands in the Province, on both sides of the Red River between the International Boundary and Lake Winnipeg, along the south side of the Assiniboine River between Winnipeg and Portage la Prairie, below the Riding Mountain escarpment from the Whitemud River to Lake Dauphin and in the Swan River Valley.

The Districts were not all successful, due to peculiar topographical, engineering, political, and financial problems of the Districts. Some were dissolved in their early stages of development. Notwithstanding these problems, by 1930 approximately two million acres of land were being serviced by the Districts with debentures having been issued to the amount of $6,824,336, which represented an average cost of approximately $3.50/acre.

As mentioned, some Districts failed in their early stages, but even the ones that survived were not without problems. The problems related to claims by landowners, of not receiving benefits relative to the debenture levies, lack of maintenance and "foreign water" arising from outside the district which had to be handled in the district drains. The latter resulting from the district boundaries not encompassing a total watershed but limited to the area immediately serviced by the drainage system.

The problems in the Districts were further aggravated by the severe economic conditions in the early thirties, in 1935 the Finlyson Commission was appointed by the Province to find a mutually agreeable solution to the problems in the Districts relating to the foreign water problems, inequitable distribution of drainage levies relative to benfits, and the problem of arrears in debentures. The Commission recommended that the Province assume approximately half of the $4 million outstanding on the debenture debt, that Drainage Maintenance Districts be established, comprising essentially the former Drainage Districts, with the Province contributing one-third of the cost of maintenance. The Districts affairs were to be administered by a Board of Trustees appointed by the included municipalities with a common Chairman appointed by the Province.

The Land Drainage Arrangement Act of 1936 provided the legislative authority for the creation of the Drainage Maintenance Districts, but the responsibility for the construction or reconstruction of drainage works was not addressed in the mandate of the Boards. The Province did not accept the recommendation of the Commission concerning the payment of one-third of the cost of maintenance but limited its annual share of an amount equal to one-half of 1% of the capital expenditures in each District.

During the first five years of their existence, the Boards used the Provincial share amounting to approximately one-third of the cost of maintenance. However, during the early forties, with the advent of wet years and sharply increasing construction costs, the municipal share increased year by year against the fixed contribution of the Province.

In 1947, as a result of representations from the Municipalities in the Districts, the Province appointed Mr. M. A. Lyons, a form Deputy Minister of Public Works, to examine the financial contribution of the Province to the Districts and the problem of foreign water which had increased due to the construction and improvements to drainage works in the municipalities in the portion of the watershed outside the Districts.

The Lyons Commission recommended that the Province assume:-

(a) two-thirds of the cost of construction and maintenance of drains carrying foreign water.

(b) one-third of the cost of construction and maintenance of drains intercepting and carrying local water originating in the District.

(c) the Province assumes 100% of the cost of reconstruction of major floodways carrying foreign water through the Districts in the Red River Valley.

In 1952, the Province accepted the financial formula of the Lyons Commission for its share of the maintenance works in the District, as well as, initiated a reconstruction program on the Floodways which carried the major flows from the escarpment through the valley. During the next 14 years the 24 Drainage Maintenance Districts as originally formed in 1936 operated very effectively under the Boards with engineering services being provided by the Province. In addition, four new districts were formed in areas not previously in Drainage Districts. In reconstruction or construction of drainage works still required the negotiation of cost-sharing between municipalities inside and outside the Districts.

In 1964, the Manitoba Royal Commission on Local Government Organization and Finance presented its report recommending major changes in the organization of municipal boundaries. One of the underlying principles of the report was that there should be a clear distinction between responsibility for services between the Province and the municipalities. The municipalities should bear the full cost of direct services with the Province assuming the costs where services provided a wider provincial benefit. In 1966, the Province instituted such a system in respect to drainage services by the adoption of the Provincial Waterway System. The basic criteria for the declaration of Provincial Waterways is based on the designation of drains in the system, with the 1st and 2nd order drains being those in the upper reaches, and the 3rd order and higher being those in the lower reaches, and serving in the majority of situations more than one municipality. At the time of initiation of this policy, it was anticipated that the Province would plan and carry out the construction or improvements to the drainage systems on a watershed basis, taking into consideration the overall Provincial priorities, as well as, the local municipal requirements. Since the inception of the policy experience has shown, that notwithstanding a striving for co-operation in respect to timing of projects, full co-ordination, between the Province and the municipalities on the development of systematic maintenance and improvements on drainage networks has not been realized.

By the early 1970's, it became clear that some method was required to evaluate the economic benefits from drainage improvment projects. The design formulas that were in use only considered topography and were based on experiences in the Red River Valley in Minnesota and North Dakota. The Province commissioned the University of Manitoba's Department of Agricultural Economics to carry out a pilot study on drainage areas in the Red River Valley. It was found that data available could be used to relate drainage improvement costs to economic return. In 1973, an extended study was undertaken to apply the methodology throughout agro-Manitoba. A report entitled "Benefit-Cost Evaluation of Improved Levels of Agricultural Drainage in Manitoba" was completed in 1975.

This report provided the basis for the Branch to determine the benefit-cost ratio for proposed drainage reconstruction projects in the Province. The rationale was also used to encourage the development of projects on the complete system approach from the on-farm drains, through the laterals to the main trunk drains to consistent standards and within a reasonable time frame. The availability of the benfit-cost ratios on a number of competing projects, within the present budget restraint period, can be considered as one factor in priorizing projects.

In 1979, Canada and Manitoba signed the Subsidiary Agreement on Value-Added Crops Production, in which $7 million were allocated to remove the constraint of inadequate drainage on production in four watersheds lying in the Red River Valley. The Agreement required that the economic feasibility of each project had to be demonstrated and made reference to the technology developed in the above referenced Report.

Over the past five years, projects on the systems basis have been analyzed and designed on using rationale developed in the Report with the main drains being constructed under the Agreement. The municipalities in the watersheds have signed agreements with the Province requiring them to construct the necessary laterals, and to encourage the landowners to develop the necessary on-farm drains. It is expected that by the termination of the work period under the Agreement on September 30, 1985 approximately $6,450,000 will have been expended under the Agreement.

Under the Agreement to encourage local understanding and commitment to the systems approach, each project was developed under a local advisory committee co-chaired by a regional representative from the Department of Agriculture and the Department of Natural Resources. A demonstration project was included on the Domain Drain watershed immediately southwest of Winnipeg. A hydrometric and meteorological network was installed to monitor rainfall and runoff in the Domain watershed and the adjacent Manness Drain watershed, where no improvements have been carried out, to act as the control. It is anticipated that the monitoring of these watersheds will provide the data to illustrate the advantages of systematic drainage system development on a rational basis to reach the maximum benefit-cost ratio selected in the design parameters.

In December, 1982, at a two-day seminar attended by key personnel from the Department of Agriculture and the Water Resources Branch, all aspects of the existing drainage programs in the Province were examined in the light of today's needs in the agricultural sector of Manitoba's economy. The seminar clearly identified that the removal of excess summer rainfall from crops was an important requirement to improve the production on five thousand acres of land in Southern Manitoba. The seminar also focused on the types of delivery systems which had evolved over the past 100 years in the Province and recommended

and the landowners should be instituted on a watershed basis, through a district approach managed by a local board.

Since that time progress has been made through a co-operative effort between both Departments to provide the framework to effect the changes required at all levels to implement the recommendations from the seminar.

In respect to the planning, design and building of systems to remove excess precipitation, four standards relating to the soil capabilities have been proposed. These standards are not applicable to organic (peat) soils or to wet sands which require more precise regulation of surface water, as well as, groundwater and soil moisture. The four standards are:-

a)	Special Crops:	little tolerance to excess moisture. Crops losses will occur within a few hours.
b)	Cereal Crops:	limited tolerance to excess water. During the active growing season crop losses will occur within 36 hours.
c)	Forage Crops:	moderate tolerance. These crops can withstand flooding for up to four days during the active growing season without showing yield reductions.
d)	Pioneer Standard:	applied to native hay and pasture lands. Yields may decrease with flooding. However, excess water should be drained within ten days during the active growing season.

The attached map of Southern Manitoba displays, in broad terms, how the standards would be applied for improvement of drainage services in Southern Manitoba.

The present split jurisdiction between the Province and the municipalities should be phased out and replaced with Districts having boundaries coincident with natural watershed boundaries. The development within a District would only be permitted to occur within the framework of a district management plan.

The present Conservation Districts Act, under which there are five operating Districts is the vehilce, with some modifications which can be used to initiate the formation of districts. This approach would require the active promotion of a district concept along with the phasing out of the present provincial waterway policy.

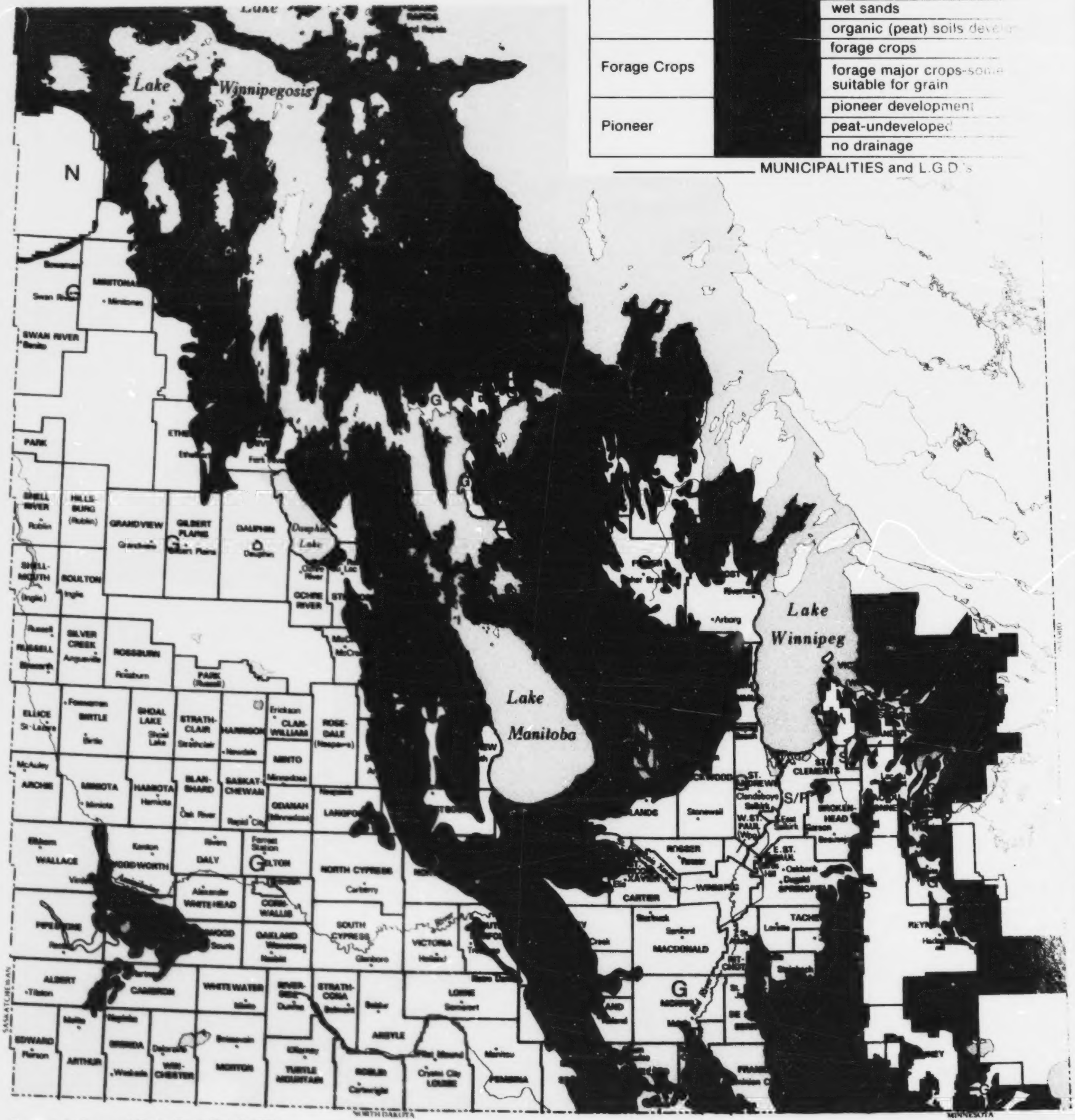
To provide a focus and visibility to this district concept provision was provided in the 1984/85 Budget of the Department of Natural Resources for the creation of a Conservation District Commission under the Minister to provide technical and administrative services to the Conservation Districts. Provision will be made for information and educational service support, both for the existing Districts, as well as, the development of strategies for the promotion and development to new districts.

The legislative mandate for management, allocation and development of the water resources of Manitoba is contained in the Water Rights Act. A revised Act was recently passed by the Legislature, which will require the continuation of the issuing of licences for water use, but also for works which "divert" water. At present the necessary regulations are being developed with the objective of putting in place an effective and fair system to examine and appraise within a reasonable time frame applications for construction of works.

This overview has endeavoured to provide in capsule form the evolution of the development and management of the agricultural drainage systems in Manitoba. At each time a change of direction was made, it appeared to meet the needs for improvements within the economic and political conditions of the time. Throughout the period, however, continued expansion and improvements to the system have been realized, and today there are approximately 27,000 km of man-made drains of which about 5,000 km are under the jurisdiction of the Province. The majority of the drains are located in the clay soils with the highest productivity. The estimated present value of the drainage infrastructure is estimated to be approximately $500 million.

FEBRUARY, 1984

PROPOSED STANDARDS FOR THE REMOVAL OF EXCESS RAINFALL


Lake Winnipegosis
N
SWAN RIVER
MINITONAS
PARK
ETHELBERT
SHELL RIVER
HILLSBURG
GRANDVIEW
GILBERT PLAINS
DAUPHIN
Dauphin Lake
OCHRE RIVER
SHELLMOUTH
BOULTON
RUSSELL
SILVER CREEK
ROSSBURN
PARK (Russell)
ELLICE
BIRTLE
SHOAL LAKE
STRATHCLAIR
HARRISON
CLANWILLIAM
ROSEDALE
MINTO
ARCHIE
MINIOTA
HAMIOTA
BLANSHARD
SASKATCHEWAN
ODANAH
LANGFORD
WALLACE
WOODWORTH
DALY
ELTON
NORTH CYPRESS
WHITEHEAD
CORNWALLIS
PIPESTONE
OAKLAND
SOUTH CYPRESS
VICTORIA
ALBERT
CAMERON
WHITEWATER
RIVERSIDE
STRATHCONA
LORNE
EDWARD
ARTHUR
WINCHESTER
MORTON
TURTLE MOUNTAIN
ROBLIN
LOUISE
PEMBINA
ARGYLE
Lake Manitoba
Lake Winnipeg
ST. ANDREWS
ST. CLEMENTS
BROKENHEAD
ROSSER
CARTIER
MACDONALD
TACHE
SPRINGFIELD
MORRIS
G
S/P
SASKATCHEWAN
NORTH DAKOTA
MINNESOTA
ONTARIO

LEGEND

STANDARD	SYMBOL	DESCRIPTION
Special Crops	■	special crops
Cereal Crops	G	grain-major crops
	■	grain-major crops but som areas only forage
	■	wet sands
	■	organic (peat) soils develo
Forage Crops	■	forage crops
	■	forage major crops-som suitable for grain
Pioneer	■	pioneer development
	■	peat-undeveloped
	■	no drainage

——— MUNICIPALITIES and L.G.D.'s

Cartography by: Surveys and Mapping Branch, Manitoba-1980

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AGRICULTURAL LAND DRAINAGE - AN INTERPROVINCIAL VIEWPOINT

by R.B. Godwin, Executive Director
Prairie Provinces Water Board

Presented to: The Third Annual Western Provincial Conference
Rationalization of Water and Soil Research and
Management Agriculture Land Drainage

Some of the land drainage in the provinces of Alberta, Saskatchewan, and Manitoba may create problems in adjacent provinces. The Prairie Provinces Water Board is aware of the potential problems that might arise as a result of this type of drainage, and is dealing with them.

When the Master Agreement on Apportionment, reconstituting the Prairie Provinces Water Board, was signed on October 30, 1969 one of the Board's duties was:

> "to develop recommendations on other water matters, in addition to problems of water quality, referred to the Board by any party hereto including the review and analysis of existing information and the requesting of additional studies and assistance by appropriate governmental agencies to provide information for formulating its recommendations,".
> Article 4c, Schedule C, Master Agreement on Apportionment.

Interprovincial drainage is dealt with as part of this responsibility.

Interprovincial drainage problems had been mentioned in previous Board meetings but the first direct reference to the subject was at Meeting No. 20 on May 23, 1979. It was pointed out that the effects of authorized and unauthorized drainage were not included in a natural flow study of the Assiniboine River basin although similar drainage works in the Souris River basin caused significant changes to the flow. The members suggested that research studies be conducted on representative drainage areas to document the effects of various levels of drainage on downstream flows. Estimates of the consequences of such drainage development could then be made before such works were approved.

The Board agreed that there is a need; to define the problem areas to be included in drainage studies, to review the research work done to date and to investigate sources of funding to support continuing studies of this type. The Environment Canada member agreed to have his staff conduct a literature survey to establish what has been done to determine, and to document, the effects of drainage on downstream flow and to report on procedures that might be used to fund future studies under federal research programs. The results of that analysis were presented at Meeting No. 22 on November 21, 1979. The member for Environment Canada pointed out that literature on the subject is scanty and that past research is poorly documented, indicating regionalized results that are inconclusive or contradictory. It was suggested that researchers may have had difficulty in isolating drainage configuration as a causitive factor when soils, topography and climate also play such an important part in the runoff equation. Some researchers suggested that regionalized concepts could not be developed and that each drainage situation must be treated as an individual case.

The Board, based on this information, agreed that the COH (Committee on Hydrology should, after consulting with hydrologic specialists, advise the Board on how an applied hydrologic research program might be developed to "determine the effects of artifical drainage on downstream flows in prairie streams."

The subject was discussed by the COH at Meeting No. 29 on December 12, 1979 and a letter report was prepared for the Board based on these and subsequent Committee discussions. This letter report, entitled "Applied Hydrology Research to Determine the Impact of Artificial Drainage on Downstream Flows", noted that the Hydrology Branch of Saskatchewan Environment has developed a procedure that may be used to determine post drainage runoff peaks and volumes and that the National Hydrology Research Institute of Environment Canada has agreed to undertake a preliminary survey of agricultural drainage problems. The Committee then recommended to the Board that:

1. The Board, acting through the COH, maintain an watching brief on the drainage research studies presently underway provincially, federally and in the Red River Basin in the United States,
2. The Board, as an interim working procedure, use the approach developed by Saskatchewan Environment to assess post drainage runoff problems,
3. Each member agency continue to inform the Board, through its standing committees, of the agency's activities on the assessment of drainage impacts.

The Board agreed with these recommendations at Meeting No. 26 on November 18-19, 1981 and directed the COH to recommend special procedures that may be adopted to permit the Board to maintain a watching brief on drainage projects that may have a significant impact on the quality and/or quantity of flow in interprovincial streams.

The Committee on Hydrology prepared a second letter report entitled "A Recommended Procedure to Deal with the Impact of Artificial Drainage on Downstream Flows". This report recommended a four step approach:

1. The Board should designate the COH to monitor drainage activities in each province and to advise the Board of any drainage activities of potential concern to any downstream province,
2. The provincial COH members will annually report to the COH on drainage activities in each interprovincial basin, and will bring to the attention of the COH any reports on projects that may significantly affect flow at an interprovincial boundary.
3. Provincial COH members will investigate complaints on drainage activities that fall outside of normal approval procedures and involve more than one province,

4. Agencies will bring to the COH, for discussion and analysis, reports on studies to assess the impact of drainage on downstream flows.

The Board, at Meeting No. 31, on November 8, 1983 accepted the COH report and directed the Committee to provide reports on drainage activities at future Board meetings. The Board also suggested that the COH should be prepared to modify the proposed method in the future if deemed necessary.

The three provincial members of the COH are now preparing a standard format for reporting drainage projects of interprovincial interest. The projects will be listed, checked and ammended regularly by provincial members. After review by the COH the project listings will be regularly reported to the Board.

In an ideal world this would all be completed before any drainage problems developed, but our world is not ideal. The Board is now dealing with a problem connected with interprovincial drainage from the Saskatchewan RMs of Churchbridge and Langenburg to the Manitoba RMs of Shellmouth and Russell. It was referred to the Board at Meeting No. 23 on May 16, 1980. The Manitoba member, in submitting this drainage problem to the Board, noted that the RMs of Shellmouth and Russell have been unable to reach agreement with the neighboring muncipalities of Langenburg and Churchbridge regarding the responsibility for upstream works or on methods that might be used to cost-share the work required to handle increased flows in Manitoba.

The Secretariat formed a Task Force and, after a field tour of the area and discussions with the four RM councils, recommended the following course of action.

1. Saskatchewan in a report to the Task Force, will define the natural drainage area tributary to the border points prior to development, the area contributing, and the area that might potentially contribute when drainage is more fully developed in future years. The impact of progressive changes in drainage area on the magnitude of flood flows at the Saskatchewan-Manitoba boundary will be estimated.

2. Manitoba, based on the Saskatchewan report, prepare a report for the Task Force estimating the improvements needed to transport these flows through the drainage systems, without causing increased flooding.

3. The Task Force will suggest an equitable method of sharing the responsibility for this drainage among the affected jurisdictions.

4. These proposals will, after review by the COH, be submitted to the Prairie Provinces Water Board. It is hoped that the resulting recommendations will form an appropriate mechanism for resolution of similar inter-jurisdictional problems.

This task is not completed but we are optomistic that the results will provide a usable case history that may be used as a standard for future such disputes.

The Board's efforts connected with agricultural drainage may be summarized as follows. Firstly, a policy has been developed that enables the Board to maintain a watching brief on interprovincial drainage and to ensure that the Board is aware of progress made in analyzing the effects of drainage on downstream hydrographs. Secondly, the types of drainage and the size of drainage that might have interprovincial effects are documented on an ongoing basis. Thirdly, the drainage problem between the RMs of Langenburg and Churchbridge, Shellmouth and Russell provides an example of how the procedures might work when future problems are identified. Fourthly, and lastly, when new and better techniques are developed these procedures will be modified to take advantage of such advances.

SESSION II

Soil-Water-Plant Relationships

Session Chairman: G. C. Jenkins

Subsurface Drainage in Alberta

Prepared by:

B. A. Paterson[1] and N. E. Jensen[2]

For Presentation to:

The Third Annual Western Provincial Conference
on
Rationalization of Water and Soil Research and
Management of Agricultural Land Drainage

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Lethbridge, Alberta

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Jensen Engineering Ltd.
Olds, Alberta

SUBSURFACE DRAINAGE IN ALBERTA

INTRODUCTION

In Alberta, problems related to excess moisture have been a common and long standing problem with farmers throughout the agricultural areas. Until recently however, with land prices relatively low, it was easier and cheaper to acquire new lands to replace those areas taken out of production because of excess water. Over the past five to ten years this attitude has changed. Higher land prices, larger farm equipment and the trend towards optimizing production have all contributed to an increased interest by farmers to control and reclaim lands affected by excess water.

Around 1975, as a result of this interest in reclamation, the initial development of the subsurface drainage industry in Alberta began in the irrigated areas of southern Alberta. Since that time, the industry has expanded into many areas of the province and appears to be a promising alternative to surface drainage for on-farm control and reclamation of saline and waterlogged soils. This paper will attempt to provide an overview of existing and potential subsurface drainage development throughout Alberta.

BACKGROUND

Prior to 1975, the use of subsurface drainage in Alberta was generally restricted to the installation of deep (2.5 m - 4.0 m) interceptor systems to prevent irrigation canal seepage from spreading onto farmers lands. These drains consisted of either clay or concrete pipe, were installed with backhoes and required considerable hand labor. Because of the very high costs, the number of these drainage systems installed annually was small and nearly all were government funded.

During 1975, the first large scale drainage project in Alberta was installed using corrugated polyethylene drain tubing placed at relatively shallow depths (< 1.8 m). The project was designed to reclaim approximately 72 ha of saline and waterlogged land on the LK Ranch property near Bassano and consisted of approximately 45,000 m of 100 mm and 150 mm drain tubing. As a result of the favorable reclamation rates achieved on this and other research sites initiated by Alberta Agriculture, shallow subsurface drainage has developed into an accepted methodology for controlling and reclaiming saline and waterlogged soils within the irrigated areas of Alberta. In Alberta, two companies (Big 0 and Daymond Ltd.) began manufacturing corrugated plastic drain tubing, in Taber and Calgary respectively for the agricultural drainage industry. In addition a number of contracting companies were formed or moved in from Ontario and Quebec to install the subsurface drainage systems.

From 1975 - 1978, a variety of drainage installation equipment was used for installation of the subsurface drainage. The first machine to be used was a Barth chain or ladder trencher (Figure 1) which has a capa-

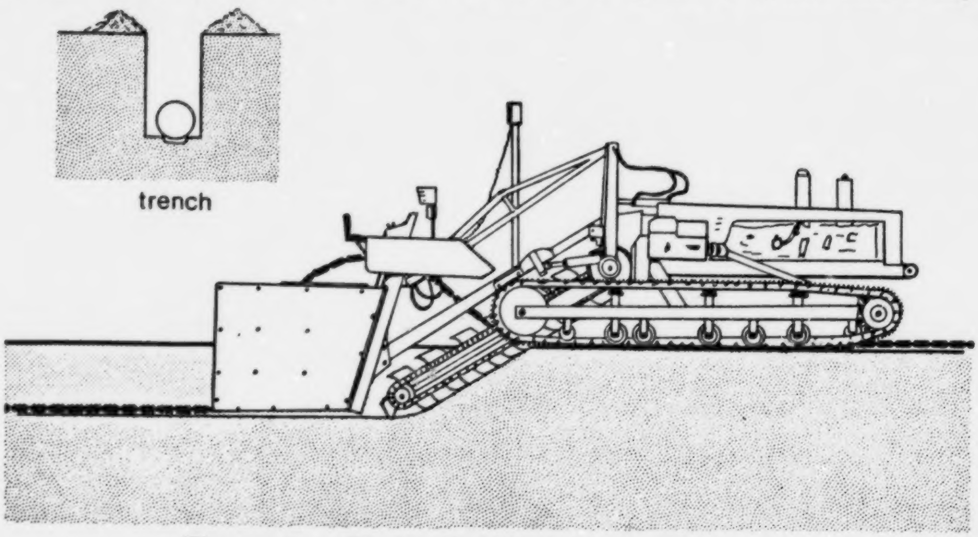


Figure 1 - Chain (Ladder) Type Trencher

bility of installing drain tubing to a maximum depth of approximately 1.8 m. This unit was found to be totally unacceptable because it was not able to handle the fine textured soils, rocks and relatively deep depths required to install the drains for good salinity control. In its place a number of Speicher wheel trenchers (Figure 2) were brought in from eastern Canada by drainage contractors. These machines have a much slower rotation of the digging wheel than the high speed ladder trenchers and were therefore better able to handle rocks and the clayey soil conditions. Unfortunately, over longer time periods (two to four years), these machines suffered the same fate as the ladder trenchers. They were simply not designed to carry out prolonged installation of drains at the deeper depths.

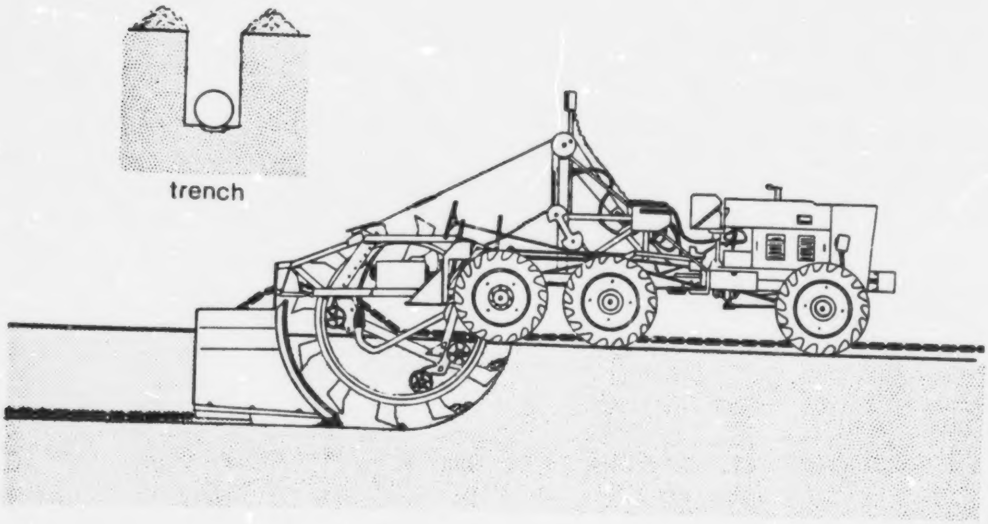


Figure 2 - Wheel Type Trencher

The trenchless plow (Figure 3) has proven to be the most suitable machine for the subsurface drainage installation needs of Alberta. A number of different styles of plow including; the Badger, Krac, Wedge and Barth, have been used in Alberta and all appear to be well suited to the variable soil conditions and drainage requirements. Because of the heavy weight of most of these units, most contractors have found that a separate winch machine is necessary for nearly all drainage projects.

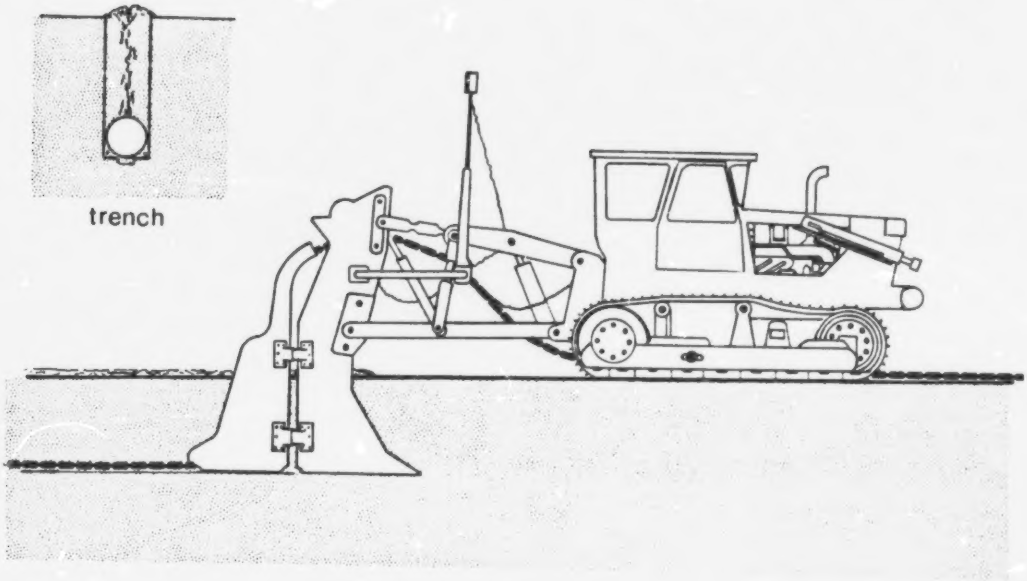


Figure 3 - Trenchless Plow

Regardless of the type of drainage machine used, it is important that all units be equipped with an automatic laser grade control apparatus and power feeder to prevent unnecessary pipe stretching (Figure 4). These additions are especially important for the high speed drainage plows.

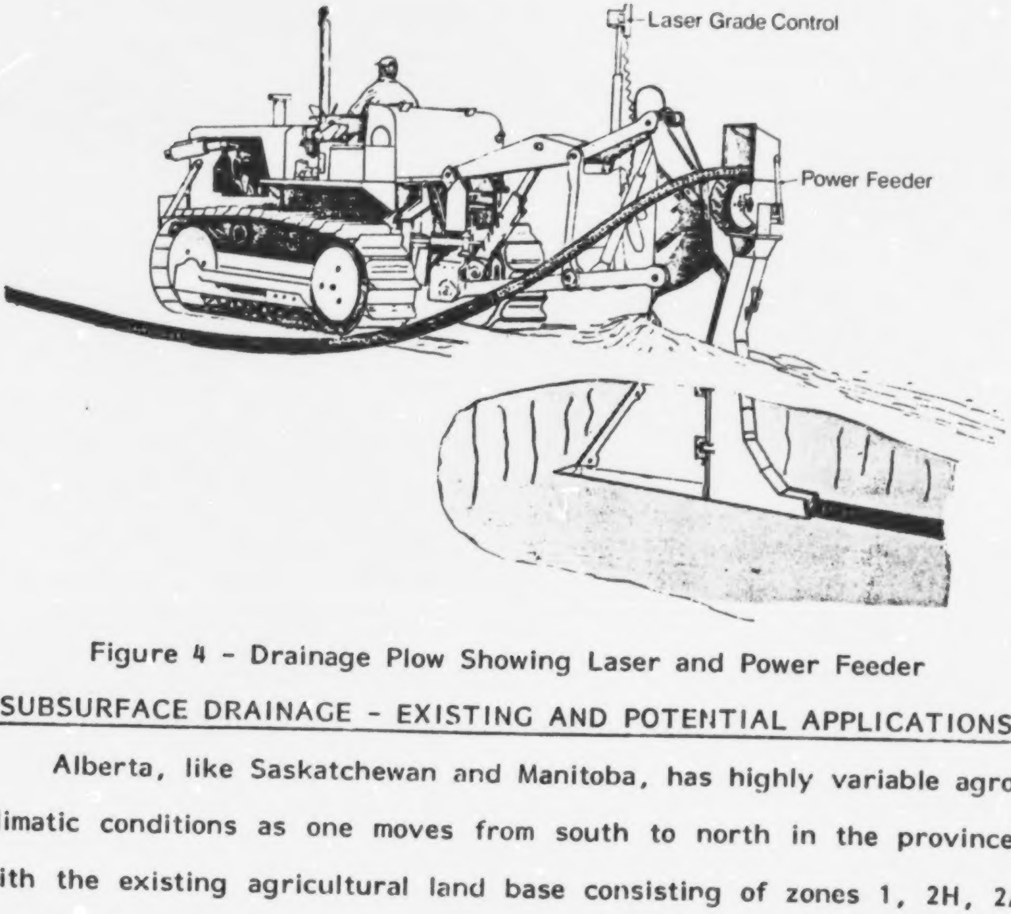
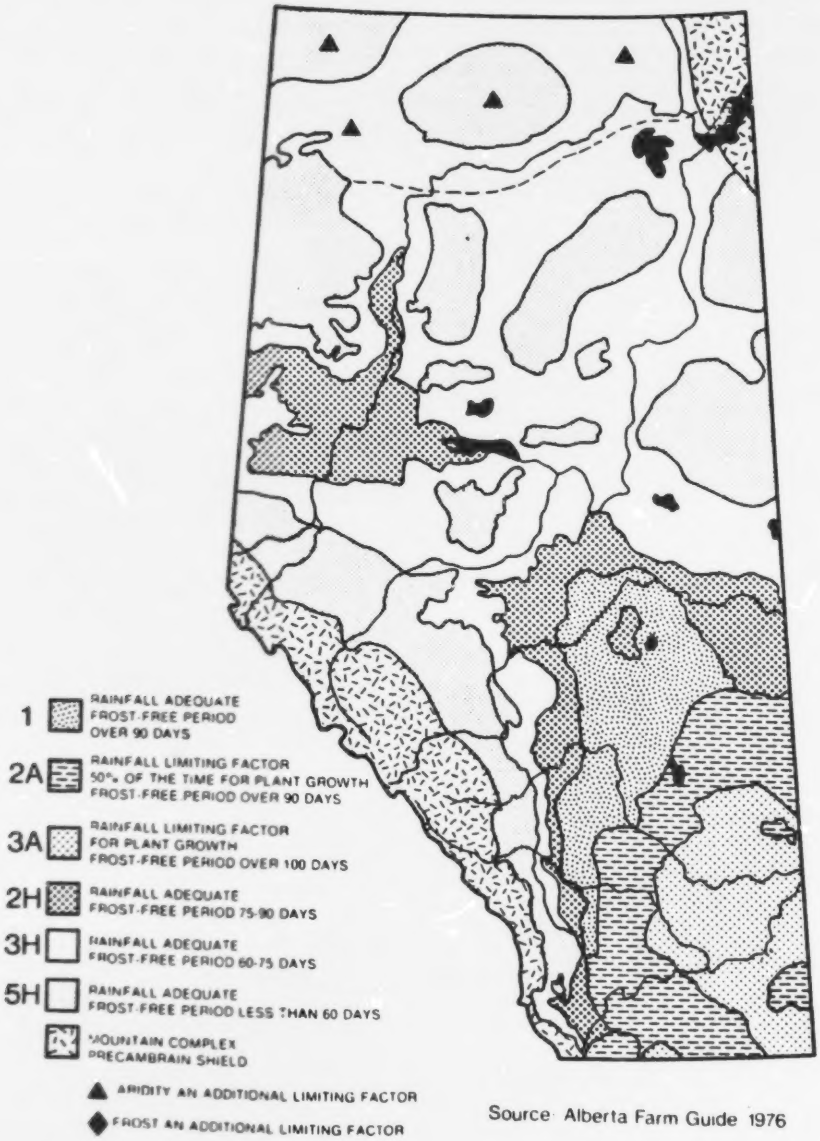


Figure 4 - Drainage Plow Showing Laser and Power Feeder

SUBSURFACE DRAINAGE - EXISTING AND POTENTIAL APPLICATIONS

Alberta, like Saskatchewan and Manitoba, has highly variable agroclimatic conditions as one moves from south to north in the province, with the existing agricultural land base consisting of zones 1, 2H, 2A and 3A (Figure 5). For the purpose of this discussion on drainage, these zones can be combined to form three regions, with 2A & 3A forming Region I, zones 1 and 2H (around Edmonton) forming Region II, and 2H (around Grande Prairie/Peace River) forming Region III (Figure 6).

Farmers in all of these regions share concerns related to excess water problems, whether they are surface or subsurface in nature. However, some differences exist between regions regarding the develop-


1
RAINFALL ADEQUATE
FROST-FREE PERIOD
OVER 90 DAYS
2A
RAINFALL LIMITING FACTOR
50% OF THE TIME FOR PLANT GROWTH
FROST-FREE PERIOD OVER 90 DAYS
3A
RAINFALL LIMITING FACTOR
FOR PLANT GROWTH
FROST-FREE PERIOD OVER 100 DAYS
2H
RAINFALL ADEQUATE
FROST-FREE PERIOD 75-90 DAYS
3H
RAINFALL ADEQUATE
FROST-FREE PERIOD 60-75 DAYS
5H
RAINFALL ADEQUATE
FROST-FREE PERIOD LESS THAN 60 DAYS
MOUNTAIN COMPLEX
PRECAMBRAIN SHIELD
ARIDITY AN ADDITIONAL LIMITING FACTOR
FROST AN ADDITIONAL LIMITING FACTOR

Source Alberta Farm Guide 1976

Figure 5 - Agro-climatic Map

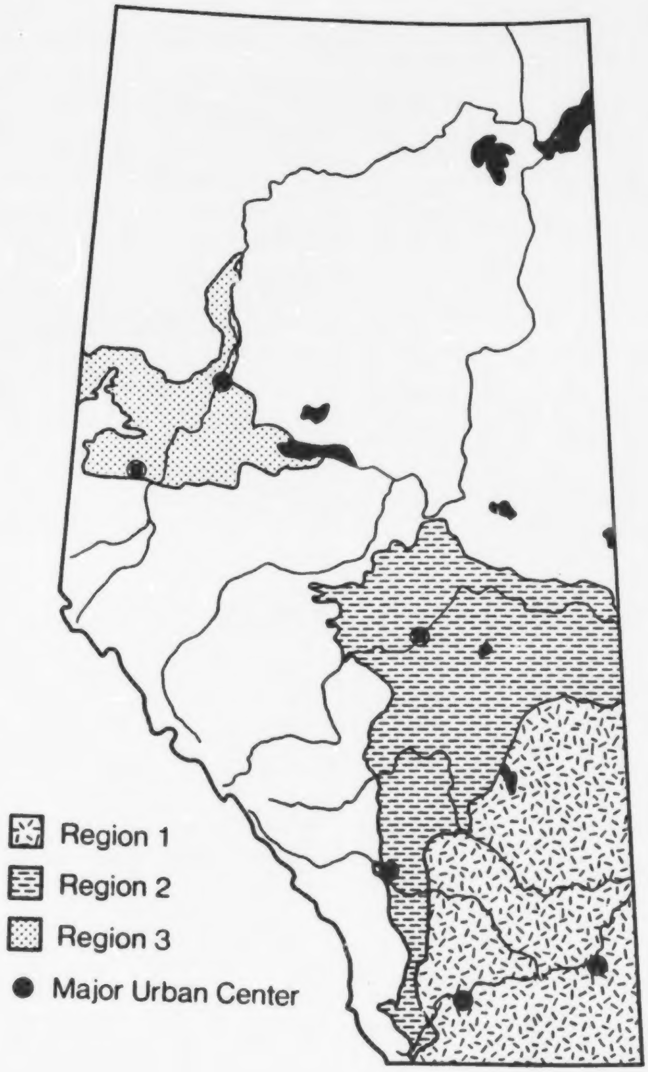

Region 1
Region 2
Region 3
Major Urban Center

Figure 6 - Drainage Regionalization Map

ment of secondary problems as a result of the excess moisture conditions. In Region I (Figure 6) for example, salinity problems resulting from excess soil moisture are a major concern to farmers and government, while salinity is generally not considered to be a serious concern in Regions II & III. Surface water problems, including permanent and temporary sloughs and potholes, represent a serious, long term problem for farmers throughout the province. The impacts of these water bodies and their control and reclamation can be quite different from region to region and even within regions because of existing soil, cropping and precipitation variables. An evaluation of subsurface drainage potential must therefore recognize both the regionalization and the problem differences within each region. For this paper, the problems related to excess moisture and their relationship to the regions are discussed as follows:

A) Salinity Control - Region I
    1) irrigated
    2) dryland
B) Surface Water Drainage - Regions I & II
C) Seeps, Bogs and Surface Water Drainage - Region III

A. Salinity Control - Region I

1. Irrigated

Essentially all of the 560,000 ha of irrigated lands within Alberta are located within Region I, including approximately 400,000 ha within the thirteen irrigation districts (Figure 7). It is presently estimated that between 60,000 - 120,000 ha of land within these districts are affected to some degree by excess salinity. The causes of these salinity problems are thought to be the result of excess water from

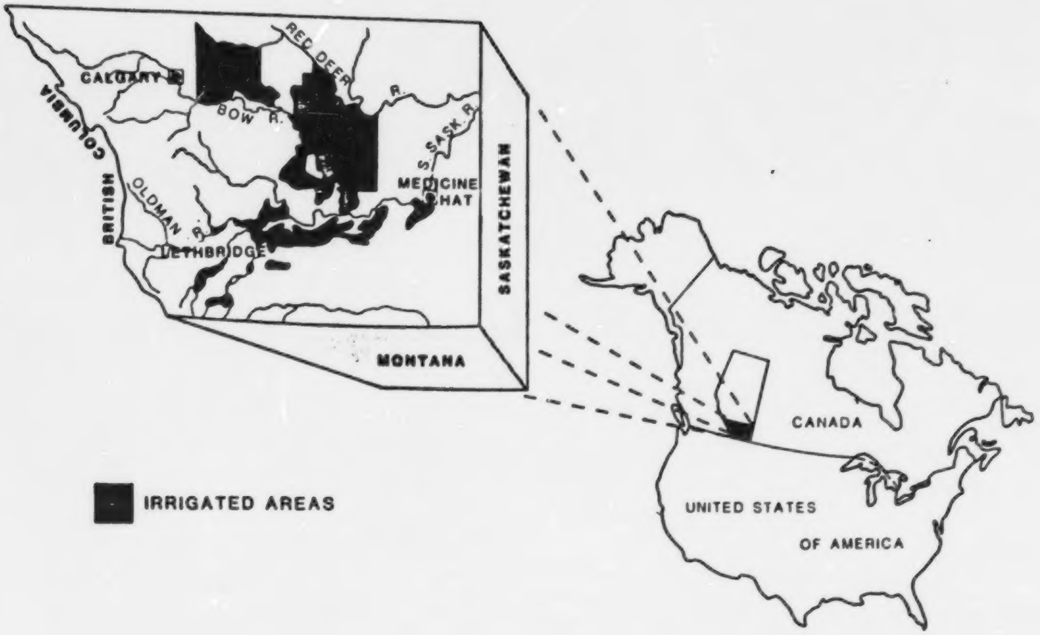

CALGARY
RED DEER R.
BOW R.
BRITISH COLUMBIA
S. SASK. R.
MEDICINE HAT
SASKATCHEWAN
OLDMAN R.
LETHBRIDGE
MONTANA
CANADA
■ IRRIGATED AREAS
UNITED STATES OF AMERICA

Figure 7 - Irrigation Districts Map

three sources; a) canal seepage, b) natural groundwater discharge and c) on-farm irrigation management. The combination of canal seepage and groundwater discharge are thought to be responsible for 80 - 90 percent of the salinity problems, with on-farm irrigation causing less than 15 percent of the problems (Paterson and Harker, 1983).

Research and on-farm evaluation has shown subsurface drainage to be a practical (Bennett et. al, 1982) and economic (Birch, 1983) method for controlling and reclaiming saline and waterlogged lands under irrigation. For most of these areas, the subsurface drainage is usually installed throughout the affected area on a set grid with drain spacings of 15 - 30 m. Installation costs are variable depending on soil types, severity of affected area, depth of drains and the amount of drain tubing required. Drainage installed throughout a 10 - 20 ha site, assuming a drain depth of 1.2 m and a 30 m spacing, will likely range in cost from $1,000 - $1,300/ha. These costs, for the most part, are borne entirely by the landowner.

In recent years considerable interest has been shown by Irrigation Districts in utilizing this "shallow subsurface" drainage concept as a means of controlling canal seepage. The traditional single deep buried interceptor drain, in addition to being very expensive, has not proven entirely effective for controlling seepage in many instances, particularly if the soils throughout the profile are highly variable. The use of multiple shallow interceptor drains is often cheaper and more effective than relying on a single deep drain. This interest by the Irrigation Districts in using drainage for seepage control has resulted in drainage contractors adapting existing drainage plows and increasing their versatility. For example, many interceptor drains are designed with gravel backfill in order to prevent horizontal bridging of seepage water. To accomodate this, drainage contractors have designed and constructed a hopper assembly which fits onto the standard drainage plow and allows gravel to be installed in the same operation as the drain tubing (Figure 8). A

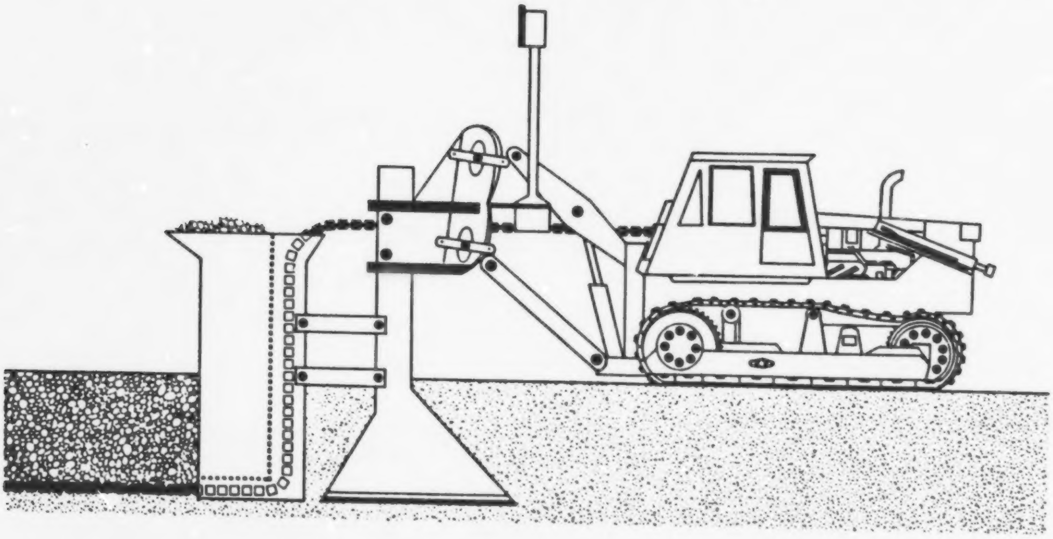


Figure 8 - Drain Installation with Gravel Backfill

second adaptation allows these machines to install plastic cutoff curtains adjacent to seeping canals (Figure 9). These curtains are installed to a

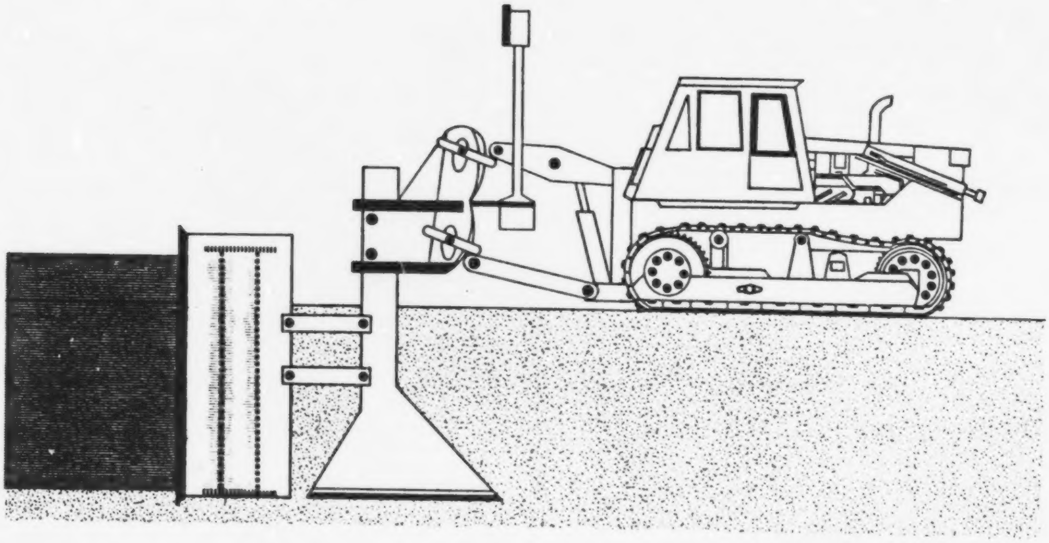


Figure 9 - Trenchless Plow for Curtain Installation

maximum depth of 2.4 m, usually in conjunction with the shallow subsurface drains (Figure 10) in order to prevent overtopping of the seepage

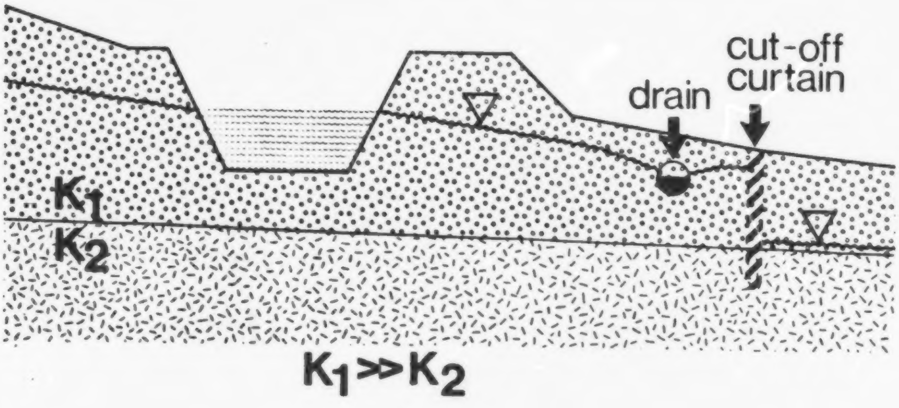


Figure 10 - Seepage Control Using Curtain & Subsurface Drainage

in cases where the full supply level (FSL) of the canal is higher than the top of the curtain. Utilizing the same basic unit to install both the drainage and the curtain has proven to be very practical for the contractor and has resulted in substantial cost savings for the Irrigation District or farmer.

Since 1975 it is estimated that 3 - 4 million meters of drain tubing has been installed throughout the irrigated areas. Assuming a spacing of 30 m for the average drainage system, this equates to approximately 8,000 - 9,500 ha of land drained. Under more conducive economic conditions, this figure would be much higher.

2. Dryland

Dryland salinity problems in Alberta have received considerable attention from farmers, associations and governments over the past five to ten years. Current estimates of the amount of land affected by dryland salinity are approximately 200,000 ha, with essentially all of this located in Region I. More significant is the fact that this figure may be increasing by as much as 10% per year (Vander Pluym, 1982). It is generally accepted that dryland salinity problems are caused mainly by the movement of groundwater from upslope recharge areas to downslope discharge areas.

Control and reclamation of dryland saline seeps by shallow subsurface drainage is not as well understood as salinity reclamation in irrigated areas. One of the keys to successful reclamation of saline soils under irrigation is the ability to apply large amounts of water to the drained soil in order to leach the excess salts through the soil profile and into the drains. Under dryland conditions this excess water is not always available on a regular basis and reclamation is likely to be slower. In spite of this however, numerous projects have been installed by farmers throughout this region on dryland saline seeps. The reclamation on these projects have been variable and generally dependent on the seriousness of the salinity problem. In areas where salinity is very high and a salt crust is visible, reclamation is usually very slow. On soils with moderate to low salinity levels in the soil profile, reclamation rates can be quite rapid. Regardless of the salinity levels however, the installation of subsurface drainage in any discharge or seep area can be very beneficial in halting the spread of the affected area and allowing farmers to work through the saline seeps without getting stuck. The cost of drainage in these areas is generally less than in the irrigated regions since most systems are installed on a random grid or as single lines through the middle of the seeps. Research is presently being carried out to determine the effectiveness and economic practicality of using subsurface drainage for control of the saline seep areas.

B. Surface Water Drainage - Regions I & II

Surface water bodies such as sloughs and potholes are a common sight throughout most of the agricultural areas of Alberta. These are most noticeable during the spring when snowmelt and spring rains combine to form shallow, usually temporary, sloughs and potholes. To the farmer, these are a major nuisance and a financial problem because they cannot be seeded with the rest of the field and, upon drying up during the summer, become a haven for various types of weeds. In many cases these temporary sloughs make up a significant part of the farmers land base and result in significant revenues losses. With the trend towards larger and larger farm equipment, these areas are looked upon as serious impediments to field operations such as cultivation, seeding and harvesting. Studies have shown that significant losses in fuel, seed, spray, etc. result from maneuvering around these water bodies, to say nothing about losses in production (Jensen, 1984). In addition, drainage of sloughs located in recharge areas is considered important for the control and reclamation of dryland salinity problems.

Over the past five to ten years farmers throughout Alberta have shown an increased interest in reclaiming these temporary slough areas. Drainage of these areas has generally involved the construction of surface drains connecting each slough area and outletting into a surface drain, natural coulee or stream. The objective was to move the water off the farmer's land as quickly as possible. While this philosophy is still true for most farmers, a changing attitude towards water management is emerging as a result of the dry and, in some instances, drought conditions which have existed in many parts of Alberta over the past four to five years. Instead of simply draining sloughs, farmers are showing more interest in consolidating water bodies and storing the water on the farm for possible re-use. This is especially true in Regions I and II (Figure 6).

Coincidental with the increased interest in slough drainage and reclamation was the introduction of subsurface drainage to Alberta. Since 1975, one company in particular (Jensen Engineering Ltd.) has designed numerous subsurface drainage projects for drainage and/or consolidation of sloughs and potholes for individual farmers throughout Regions I & II. Following is a brief description of the surveying and design procedures used by Jensen Engineering for slough drainage projects.

1. Design & Installation

Aerial photographs (Figure 11) and topographic maps (Figure 12), available from government libraries, make excellent base maps since sloughs are usually distinct and well-defined. Photographs can be

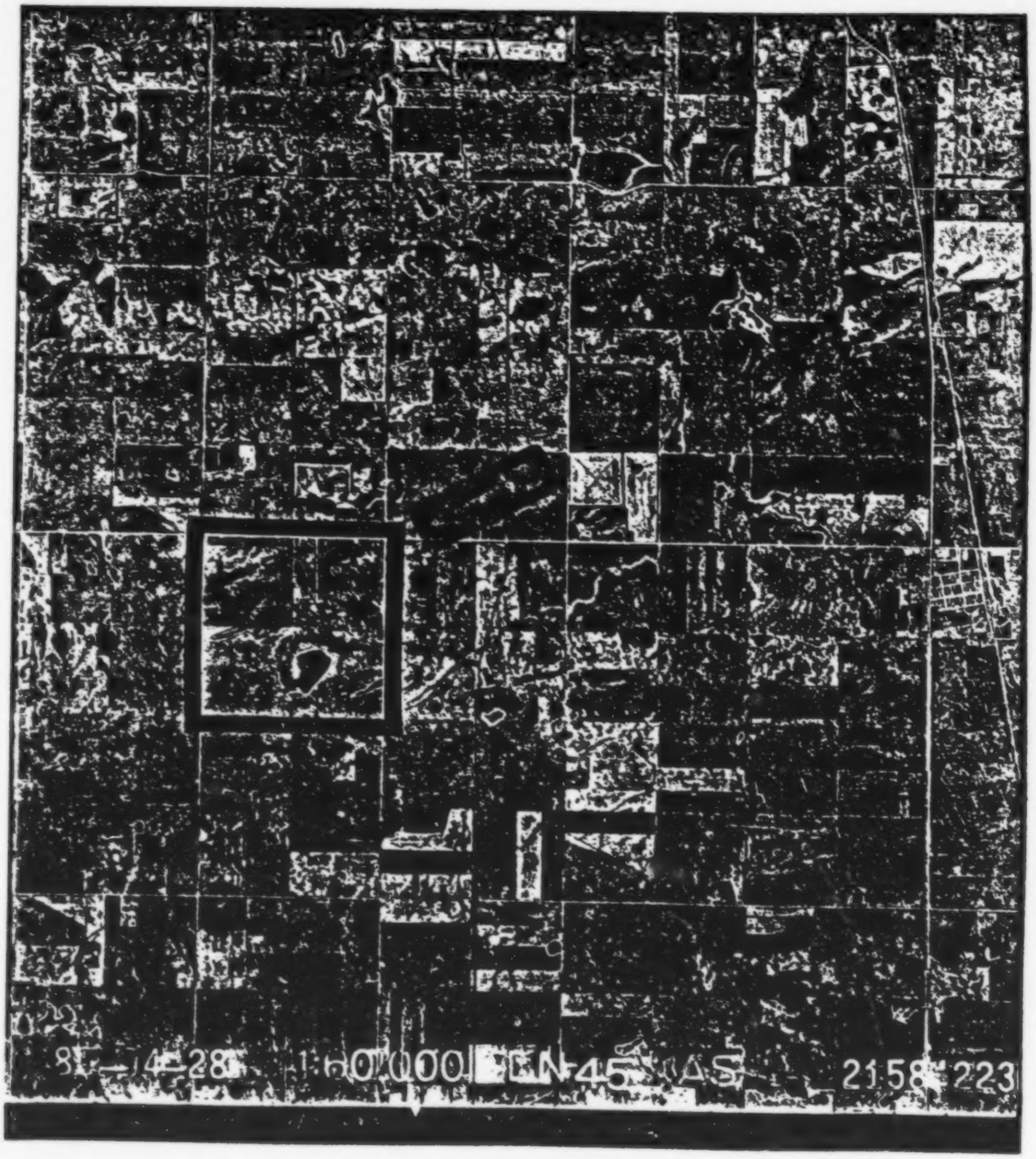

4-28
1:60000
N-45
AS
2158
223

Figure 11 - Aerial Photograph

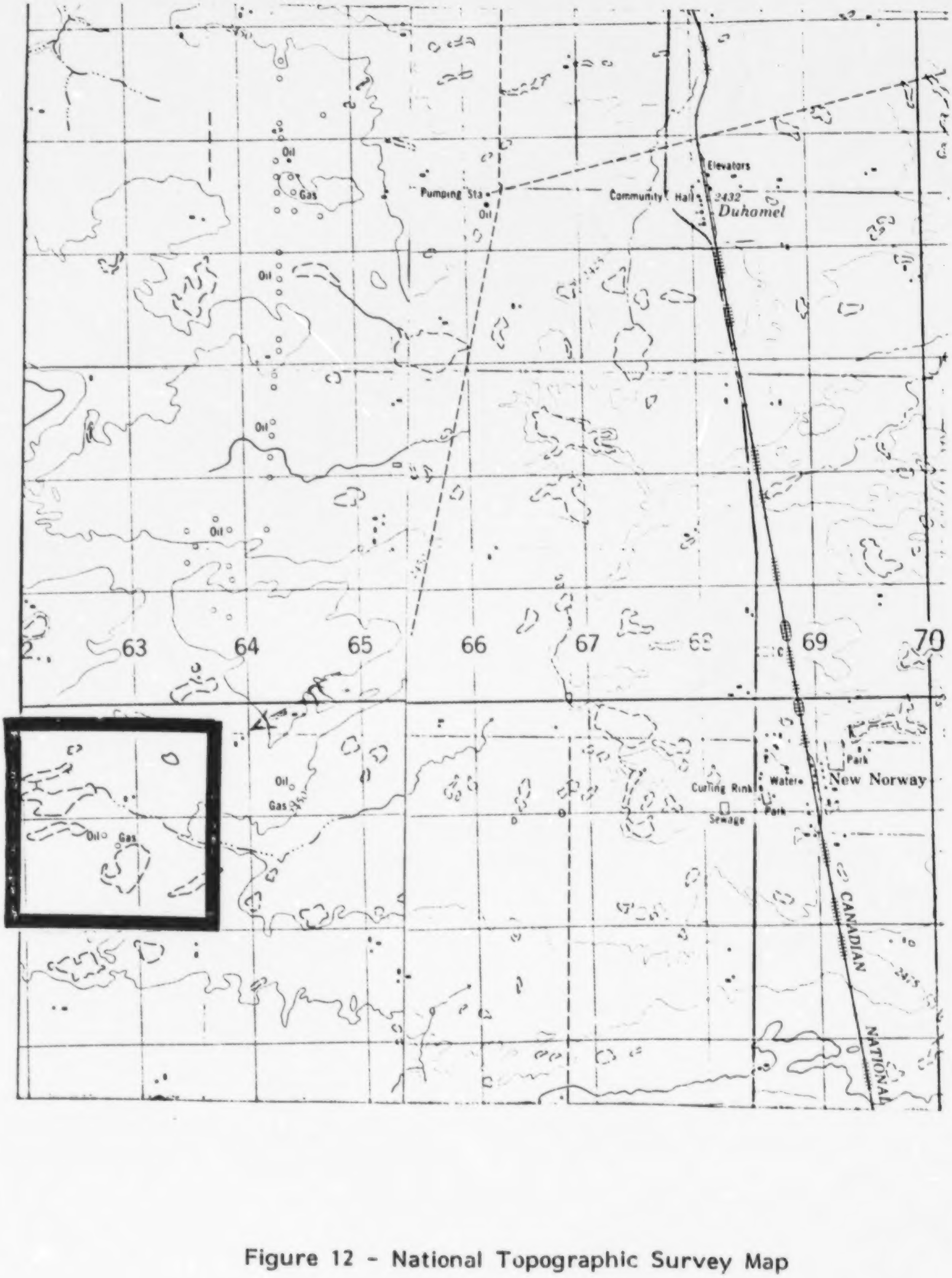

Oil
Gas
Pumping Sta
Oil
Elevators
Community Hall
2432
Duhamel
Oil
Oil
Oil
63
64
65
66
67
69
70
Oil
Gas
Oil
Gas
Park
Curling Rink
Water
New Norway
Sewage
Park
CANADIAN
NATIONAL

Figure 12 - National Topographic Survey Map

enlarged onto mylar for white-print reproduction and slough areas can be measured by planimeter on overlay grid methods. A recent innovation is a micro-computer digitizing system which rapidly enlarges, plots and calculates slough areas (Figure 13). Gas pipelines and other utilities should also be shown on the map. With the sloughs already located on the base map, a topographic survey can be conducted very economically, using a one-person laser surveying system (Figure 14). A quick reconnaissance survey is first made to establish the best routing for each main drain, then profile surveys are done using a hip-chain (stringmeter) to establish horizontal control. Based on this data, the depths of cut for the drainage system can be rapidly calculated.

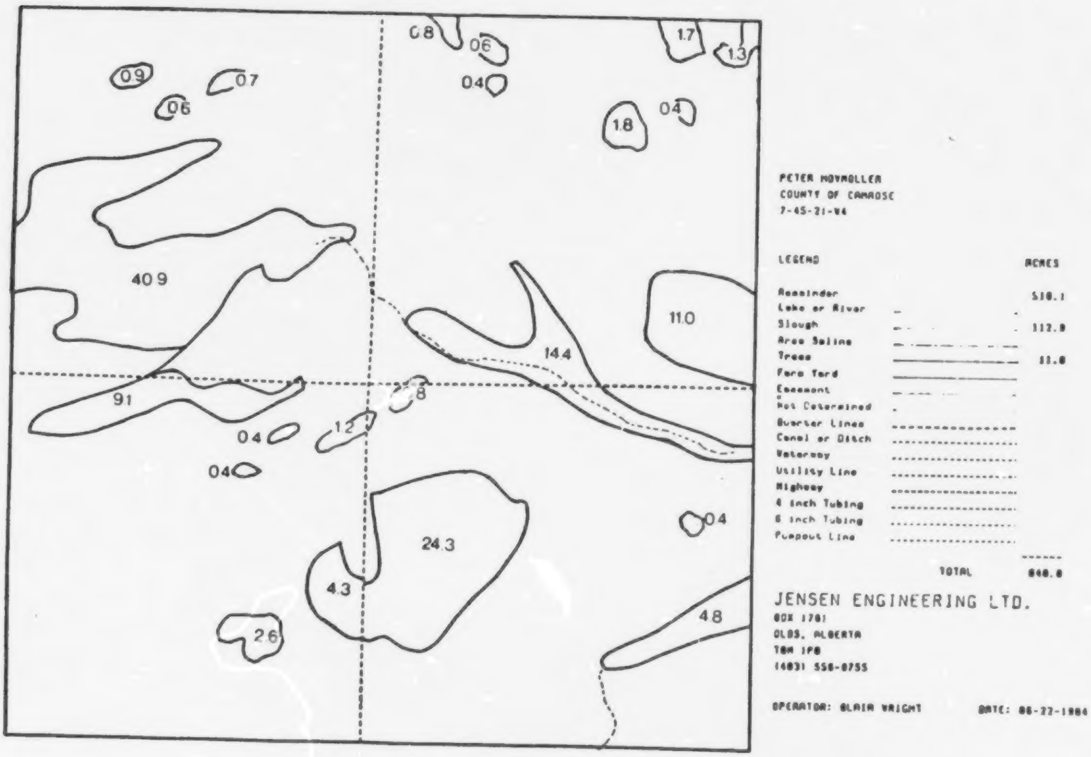

0.8
0.6
1.7
1.3
0.9
0.7
0.6
0.4
1.8
0.4
40.9
11.0
14.4
9.1
.8
1.2
0.4
0.4
0.4
24.3
4.3
4.8
2.6
PETER MOVMOLLER
COUNTY OF CAMROSE
7-45-21-W4
LEGEND
ACRES
Remainder 516.1
Lake or River
Slough 112.9
Area Saline
Trees 11.0
Farm Yard
Easement
Not Determined
Quarter Lines
Canal or Ditch
Waterway
Utility Line
Highway
4 inch Tubing
6 inch Tubing
Pumpout Line
TOTAL 640.0
JENSEN ENGINEERING LTD.
BOX 1781
OLDS, ALBERTA
T0M 1P0
(403) 556-8755
OPERATOR: BLAIR WRIGHT
DATE: 06-22-1984

Figure 13 - Computer Generated Enlargement of Figure 11

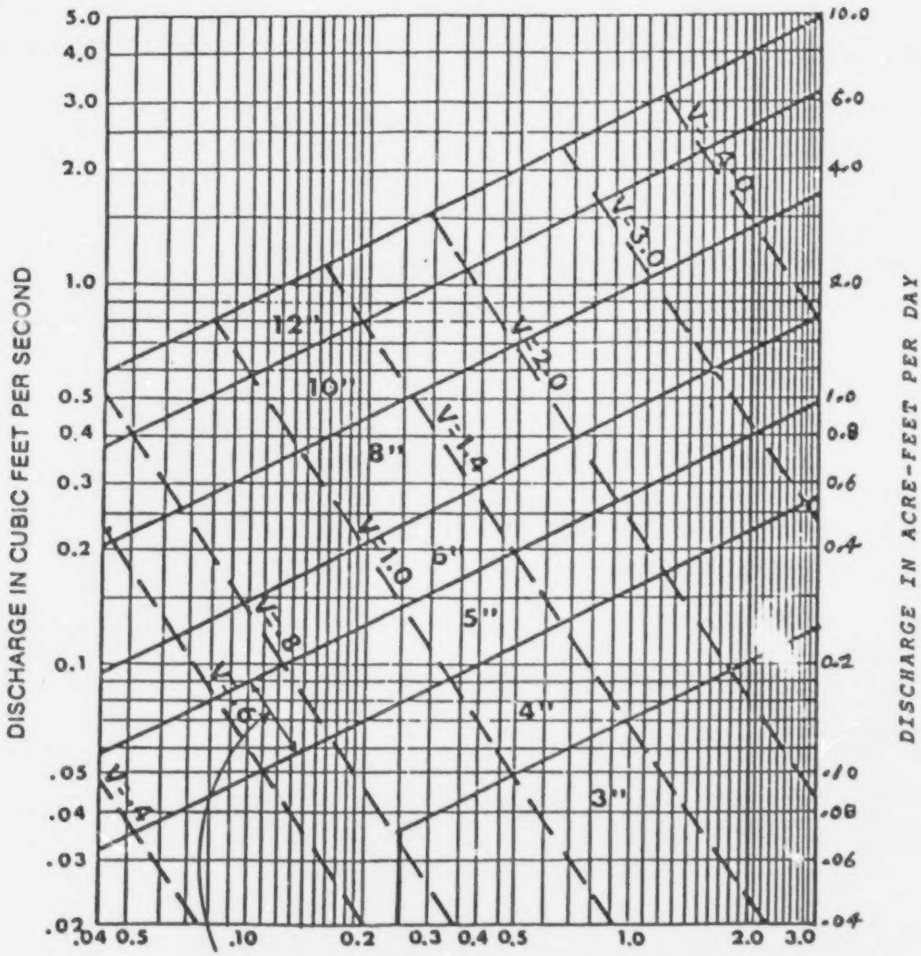
Figure 14 - Laser Command Center for Surveying

Typical drainage machines can theoretically install pipe to a depth of 1.8 m or more. However, most contractors have learned that any cuts deeper than 1.4 m should be excavated to maintain a 1.4 m maximum plowing depth and streamline the operation. A cat and scraper or Hi-Hoe is used to remove and stockpile the top section of soil, which is then backfilled after the drain is plowed in. There appears to be no limit to the total depth of cut possible using this concept. There are several examples of pipe installed to depths greater than 3 m without adverse effect.

2. Drain Design

Figure 15 is a useful nomograph for sizing corrugated plastic drainage tubing. For example: Consider a slough containing 1.2 ha-m (10 acre-feet) of water. An outlet 300 m away is 1.2 m lower than the bottom of the slough. At what grade can the pipe be installed? What size of pipe is required to drain the slough in 20 days? Answers: Assuming 0.75 m of minimum cover in the slough, the grade available = 0.49 m/300 m = 0.15%. Total water head from the inlet to the outlet = 1.2 m (not counting depth of water in slough). Effective grade = 1.2 m/300 m = 0.40%. Capacity required = $\frac{1.2 \text{ ha-m}}{20 \text{ days}}$ = 0.06 ha-m/day (0.5 acre-feet/day. From Figure 15, a 150 mm (6") pipe is required.

Chart for determining the required size of corrugated plastic drainage tubing.
(n = 0.016)



Space between lines is the range of tile capacity for the size shown between lines.
V = velocity in feet per second
Drain grade in feet per 100 feet is the same as drain grade in percent.

Figure 15 - Drain Tubing Nomograph

Soils in slough bottoms are typically heavy textured and poorly structured with very low permeabilities. Slough drainage requires a direct inlet from the bottom of the slough to the underlying pipe. Since it is surface water you are trying to remove it makes little sense to design an expensive systematic grid of drains in a slough when one pipe with a good inlet will be more effective. Early drainage designs utilized crushed rock inlets. Their appeal was that field tillage could be done right through the inlets, eliminating all field obstructions. While most of these systems performed satisfactorily for several years, a decrease in flow-rates was noted as the rock becomes mixed with soil. During the past two years, Jensen Engineering Ltd. has designed and field-tested a new inlet, constructed of PVC plastic (Figure 16). An optional sliding

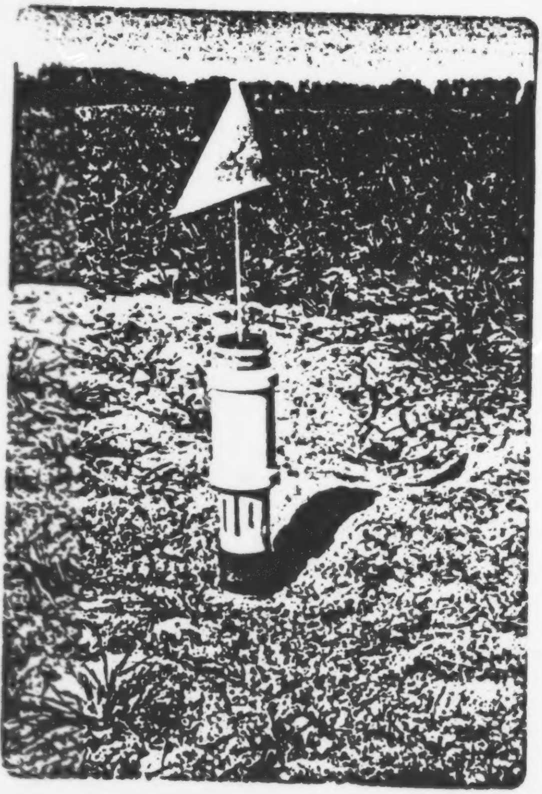


Figure 16 - PVC Drain Inlet

valve is used for backflood irrigation. The inlet is low enough to allow a sprayer to pass over it. Figure 17 shows head discharge curves for

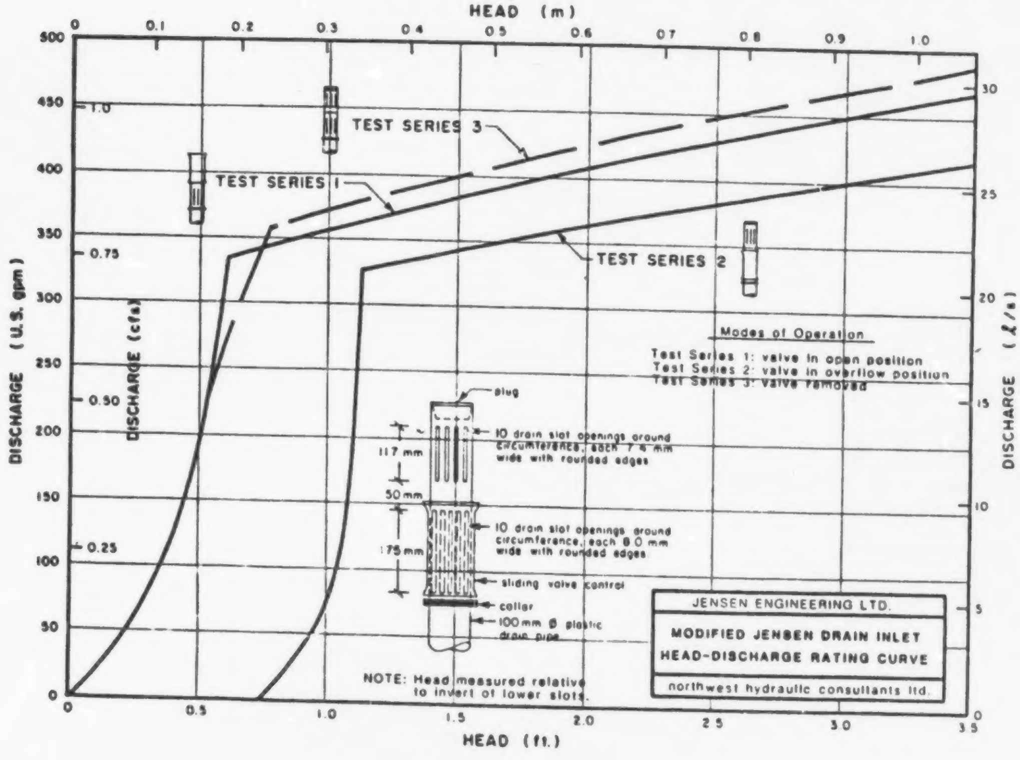


Figure 17 - Drain Inlet Head Discharge Graphs

the inlet in various modes of operation. One inlet has a greater capacity than a 200 mm drain pipe. Therefore, most sloughs can be drained with one inlet, unless variation in the slough bottom topography dictates that inlets be installed in each localized depression within the slough. An alternative is to do some shallow surface grading to bring the water to one or two strategic locations.

Slough drainage by underground pipe offers many advantages over conventional ditch drainage including; improved field efficiencies, erosion control and better control of the slough discharge rates thereby preventing downstream overloading. In general, pipe drainage is usually competitive in cost with surface ditches for draining most sloughs and potholes. However, for very large sloughs (or overland runoff) the large pipe sizes required may make the cost of subsurface drainage prohibitive. A problem which still needs to be resolved is that of freezing. Pipe systems can become blocked by ice if drainage occurs during winter Chinooks. Once frozen, the drains may not become thawed until midsummer. The new inlet design (Figure 16) may have overcome this problem since drainage cannot occur until the water reaches a certain height.

C. Seep, Bog & Slough Drainage - Region III

Problems related to excess moisture and drainage are probably more serious throughout this region than in any other in Alberta. In addition to the seeps and sloughs which create problems with spring field work and seeding operations, many parts of this region receive untimely rains in late summer/early fall which seriously delay harvesting operations. This is particularly serious for the flat-lying country where natural runoff is very slow and large portions of fields may be flooded for long periods of time. On-farm drainage has remained a high priority for farmers in these areas for many years.

Unfortunately, on-farm drainage has not progressed in any significant form in most parts of this region for many reasons including; low land values relative to drainage costs, long distance to suitable outlets (constructed or natural) and potential soil erosion problems. It is this last factor, soil erosion, which has been perhaps the most serious detriment to on-farm drainage developments. Almost all surface drains must include expensive structures and other grade control measures designed to restrict water velocities and prevent excessive soil erosion.

Subsurface drainage may potentially be the best methodology for controlling excess water on the farm, particularly in the high soil erosion areas in the southern part of this region. While the costs of this drainage are high, the potential benefits are great. Soil erosion is not a problem with subsurface drainage systems. There are additional benefits to subsurface drainage such as improved fieldwork efficiencies and gains in productive land lost because of surface drainage networks.

When discussing the benefits of subsurface drainage in the Peace River region however, the word "potential" is generally used since this form of drainage has not been extensively researched or demonstrated. To date, information is available for only two demonstration sites which were installed in 1979.

The first site, which is located near the city of Grande Prairie, has subsurface drainage installed throughout a quarter section for drainage of numerous temporary slough areas and a few seep areas. At each of the slough and seep locations, a gravel inlet or "French Drain" was constructed to facilitate rapid movement of surface water into the subsurface drainage system. A deep, natural coulee located approximately 0.5 km from the site provided excellent outlet. The farmer who owns this site reports that the drainage system performed very well and he is able to work the sloughs and seeps as we would the rest of the field. The $1,000 - $1,200/ha cost of the drainage affected acre appears acceptable in view of land values for the region plus the improved farming efficiency. It was noted however that siltation of the gravel inlets over the past two years has resulted in a slowing down of the rate of surface water movement into the drain tubing. As a result, these gravel inlets were replaced during the fall of 1984 with the new PVC inlet (Figure 16) designed by Jensen Engineering Ltd. Monitoring of this site will continue to evaluate the effectiveness of these inlets and the drainage system.

The second site, located near the town of Peace River, has a subsurface drainage system installed to control numerous peat bogs and a few sloughs located throughout the quarter section. The topography of this site is similar to the first site except that the drainage outlet is a relatively shallow open ditch and was considered marginal when the drainage was installed in 1979. In general, the subsurface drainage system has not been effective in reclaiming the affected areas on this site. The reasons for this were not fully evaluated until this fall (1984), at which time a full investigation of the drainage system was initiated by the Drainage Branch of Alberta Agriculture. The investigation, which involved the excavation of the drain tubing at various locations to determine water flow characteristics, grade control and evidence of siltation or damage, found numerous problems with crushed pipe and grade problems. In addition, the surface outlet had serious siltation problems and was totally inadequate for the drainage system. The investigation concluded that correction of the grade and drain tubing problems, plus installation of a pump to discharge the drainage effluent into the surface outlet drain will result in significant improvements to the drainage performance. Further monitoring of this site will be required once the necessary changes to the drainage system are complete.

Based on the results obtained from these two sites it appears that subsurface drainage will prove to be a practical method of reclaiming many of the areas affected by excess moisture in this region. However, considerable research and demonstration is required to fully evaluate the physical and economic parameters of this form of drainage.

CONCLUSIONS

In many parts of North America, subsurface drainage has formed an integral part of farming for nearly a hundred years and continues to gain prominence as more and more lands are brought into full production. In Ontario, Quebec and much of the eastern United States, subsurface drainage is considered a necessary management tool for water table control and economic crop production. Drain spacings as close as 5 m are required in many instances to adequately control the water table in some of the finer textured soils. Throughout many parts of the western United States, subsurface drainage for salinity control in the irrigated lands is considered as important as irrigation development itself. New irrigation systems do not proceed unless adequate drainage is provided for.

In Alberta, the availability of relatively inexpensive land in the past made it easier and cheaper to simply purchase new land rather than attempt to reclaim existing affected lands. As the size of farm machinery continues to increase, land prices move up, input costs rise and attitudes towards production optimization continue, the use of subsurface drainage will undoubtedly follow the trends in the United States and eastern Canada. Research and practical on-farm demonstration has shown its effectiveness in irrigation salinity control in southern Alberta and slough and wetland drainage in central Alberta. Continued research is needed to fully evaluate the effectiveness of subsurface drainage in dryland salinity control. For northern Alberta, where drainage problems are likely the most serious in the province, subsurface drainage will likely play an important part. However, considerable work needs to be carried out to fully evaluate its potential in this area.

REFERENCES

Apedaile, L.P. and Rapp, E., 1983. Agricultural potential for sloughs and wetlands in east central Alberta.

Departments of Rural Economy and Agricultural Engineering, University of Alberta.

Bennett, D.R., Webster, G.R., Paterson, B.A. and Harker, D.B., 1982. Drainage of an irrigated saline soil in Alberta. Can. J. Soil Sci. 62:387-396.

Birch, A., 1983. The economics of agricultural drainage: Irrigated saline soils in southern Alberta. Resource Economics Branch, Alberta Agriculutre, Edmonton, Alberta.

Holmes, N.D., McNaughton, G.R., Philips, W.E., Stolhart, J.G. and Willman, J., 1976. Alberta Farm Guide. Alberta Agriculture publication, Edmonton, Alberta.

Jensen, N.E., 1979. Farm drainage systems. Alberta Agriculture conference on Managing Agricultural Technology for Profit. Banff, Alberta.

Jensen, N.E., 1984. In Preparation. Energy costs of sloughs and potholes. Saskatchewan Agriculture Publication. Regina, Saskatchewan.

Lyster, B., 1981. Subsurface drainage: making more acres. Country Guide: 16-18.

Paterson, B.A. and Harker, D.B., 1983. Shallow subsurface drainage of irrigated glacial tills in Alberta. Summer meeting of ASAE. Bozeman, Montana.

Vander Pluym, H., 1982. Salinity in western Canada. Western Provincial Conference on Soil Salinity. Lethbridge, Alberta.

POTENTIAL OF VERTICAL DRAINAGE FOR THE DRAINAGE OF PRAIRIE POTHOLES

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Basic Principles

Vertical drainage and vertical outlet drainage, also called "Dutch drainage" (Juva) "down wells" and "down-draining wells" (Luthin) is that kind of artificial drainage in which the drainage water is disposed of into deeper, usually highly porous and with good permeability for water soil strata underlying the impermeable soil layer which causes the drainage problems above it.

The vertical drainage effect is achieved by drilling through the impermeable layer and opening a way for the water to move from above it into the more permeable and porous deeper layer. Such openings (vertical drains, vertical drainage outlets or wells) can be either fitted with tubes or pipes in a way similar to regular water wells or they can be filled with gravel or other very porous material.

It it obvious, that vertical drainage can be used only in very specific conditions, that is if there is, under the impermeable layer causing the drainage problem, a permeable soil layer which can receive the drainage water on a regular basis as required and if the impermeable layer is not too thick to make the drilling and securing of the vertical drains too costly. The receiving layer must have a good potential to dissipate or to carry away the drainage water in order not to become waterlogged itself. The possibility of groundwater pollution must be also carefully examined.

The terms "vertical drainage" and "vertical outlet drainage" indicate that there are two slightly different versions of draining water into deeper soil layers applicable to slightly different conditions and resolved by different technical arrangements (Penkava).

The case of "vertical drainage" applies to situations where the layer of the tight, impermeable soil is not too thick. It may either reach right to the top of the soil profile and in such case the water accumulating on top of it is primarily surface water or it may start at a shallow depth below surface and the water on top of it accumulates primarily in the crop root zone. In those cases a grid of relatively short vertical drains penetrating the impermeable layer and protruding some 15 cm to 20 cm into the permeable layer will be the best and most economic solution. There are many possible designs for the water-inlet top ends of the drain (Penkava) but in all cases debris and excess silt must be prevented from entering the drains. The grid spacing depends on the quantity of water to be drained and in the case of soil (not surface) water also on the permeability of the affected soil. For the drainage of smaller depressional areas one vertical drain located in the lowest spot is often sufficient.

Where the impermeable layer is too thick and simple vertical drainage would be too expensive a combination of standard ("horizontal") and vertical drainage can be used. Such combination is then referred to as a "vertical outlet drainage" system. In this case, excess water is first removed from the soil surface or from the affected top soil horizon by either ditches or subsurface drains, concentrated and allowed to spill and fall into a deep vertical outlet - a well - reaching deep into the permeable strata. An example of such system is the "North Side Minidoka Project" in Idaho (Luthin).

Use of Vertical Drainage

The most important condition for the use of vertical drainage is, as pointed out earlier, the proper stratification of the soil profile.

However, even in the presence of the required soil stratification most farmers and most consultants would probably hesitate to use vertical drainage. The reason for the reluctance is mostly a certain degree of uncertainty and risk with respect to the continuing proper function of vertical drainage and, perhaps, some concern about the possibility of polluting the groundwater system in the area.

The deciding factor, which may give an edge to vertical drainage and make it more attrative may be difficult surface outlet conditions for the traditional surface or subsurface drainage. In a field with numerous depressional, poorly drained areas separated by higher ridges moving water from the depressions to a surface outlet requires a fairly extensive, long and irregular system of drains, often very deep as they have to cross the local ridges. While the poorly drained areas certainly cause a lot of difficulties and economic losses improving them with such a complicated drainage system would not make the situation much better and vertical drainage might be much more attractive.

While the slight possibility of polluting groundwater with leached agricultural chemicals or their residues certainly cannot be completely dismissed, it should not be exaggerated especially with respect to some recent findings.

One additional benefit of vertical drainage is that it does not cause erosion and does not accelerate surface runoff as other drainage methods, especially ditching, do and is therefore better acceptable from the regional hydrology point of view.

Potential on the Prairies

The frequent occurrence of depressional topography on the Canadian Prairies where small potholes and poorly drained low areas stay in the way of mechanized large-scale farming and are difficult and costly to drain certainly create a situation which, as discussed earlier, favours vertical drainage if the soil conditions are also acceptable.

There is no doubt that removing water from the potholes and local depressions without dividing the fields with numerous snaking, branching and often fairly deep ditches, without losing productive area to those ditches and without increasing the peak runoff in the existing major drainage waterways would be a good solution of the problem.

The important question is if there are suitable soil conditions which may be quite restrictive.

Undertaking a detailed search of all available soil survey reports would be a major project especially as it would be necessary to complement it with additional local detailed investigations as the majority of soil survey report do not contain enough detailed information required in this case.

However even some fairly superficial local investigations and review of published soil surveys indicate, that there may be, and probably are, many locations where both the previously discussed topographical as well as the soil profile configuration conditions are present.

The existence of potholes and poorly drained depressions in areas with only slightly undulating or rolling topography and with generally well or fairly well permeable soils indicate that the permanent accumulation or prolonged retention of water is caused by some local soil conditions different from the soil characteristics of the general area. In most cases those localities are too small to be shown as specific soil districts in the general soil survey maps and local detailed investigations are necessary. Frequently an impermeable layer of soil is present in those locations either at the surface or near the top of the soil profile and prevents the rain and snowmelt water augmented by runoff from the surrounding area from infiltrating into the soil.

Such impermeable layers sealing the bottoms of the depressions may be a result of water and wind erosion bringing the finest soil particles and depositing them in the depression. The higher moisture caused by runoff concentration and maintained by the higher presence of finer soil particles may then trigger and support pedogenetic processes which accelerate the formation and further development of such waterholes. Such depressions are mostly relatively small but fairly numerous, the impermeable sealing soil layer is not extremely deep and there is well permeable deep soil layer underneath.

An example of such conditions can be quoted* from an area south of the Town of Roblin, Manitoba. Surface ponding is very common in depressional areas in spring and after heavy summer rains and causes problems and crop losses.

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*EILERS, R.G. 1983. Summary Report of Soil Investigations for the Roblin Waste Water Irrigation Project. Prepared for the Department of Agricultural Engineering, University of Manitoba by Canada-Manitoba Soil Survey, Winnipeg.

Generally, the soil profiles in the area show a shallow fine-textured loamy to loamy-clay layer on top of an approximately twice as thick clay layer which is apparently the reason for the poor drainage of the depressional locations. However the two layers rest on a deep layer of gravel starting at depths between 1.6 m to 4.0 m. The gravel which is very dry exceeded the drilling depth which was 11.3 m. No groundwater was detected in the gravel. This substantial layer is certainly very well suited to be a recipient for drainage waters brought down through vertical drains which could be easily installed through the relatively thin layers of clay and loam or loamy clay.

Conclusions

Conditions similar to those in the Roblin area may and most probably do exist in many other locations on the Prairies. Their identification and installation of test vertical drainage units would not only improve our knowledge of this type of drainage but perhaps open the way for a new method of reclaiming many of the prairie potholes and poorly drained depressions in a technically simple, economically feasible and environmentally superior fashion.

References

JŮVA, K. 1957. Odvodňováni Půdy. Státní Zemědělské Nakladatelství Praha 1957. Pp. 184 and 295-302.

LUTHIN, J.N. 1966. Drainage Engineering. John Wiley and Sons, New York, 1966. Pp. 176-177.

PENKAVA, F. 1966. Zemědělské meliorace v tropech a subtropech. Státní pedagogické nakladatelství Praha 1966. Pp. 61-62.

SUBSURFACE DRAINAGE OF DRYLAND SALINE SEEPS[1]

H.S.A. Vander Pluym[2], C. Livergood[3], and L. Healy[4]

ABSTRACT

In Alberta, over 700,000 hectares dryland are affected by saline seepage. This study is for the purpose of developing subsurface drainage design standards for Alberta.

Discontinuous saturated lenses occurred in the till at random, and at the bottom of the upper till. Drainage pipe on some projects depressed the water tables distinctly (.6 - .8 meter deep and over 60 meters wide). In other projects the water table was maintained at tile depth, or through natural drainage it dropped below the drain pipe. Peak discharge flows ranged from 1 to 335 L/day/meter of drain. Large flows were often the result of point sources; eg. major fractures, sand lenses, etc. Hydraulic conductivity values for clay loam tills ranged from $.1 \times 10^{-1}$ to 4.5×10^{-1} m/day. These values were high in comparison to the 1.8×10^{-2} m/day that Hendry obtained from the large fractures in weathered tills. The salt movement in the surface .9 meters of soil following the installation of tiles was mixed, but in most projects EC levels in the top .3 meters decreased.

INTRODUCTION

A recent Canada Agriculture survey indicated that over 700,000 ha of dryland are affected by saline seepage in southeastern Alberta. An additional few hundred thousand hectares of dryland saline seep occur in the area east of Edmonton. The problem results from the deep percolation of water in the upslope areas and the subsequent discharge of salinized water in the saline seep (Appendix, Figure 1). Subsurface drainage is an important control of dryland saline seepage, especially in instances of large flows, such as regional systems, and in instances of uncooperative neighbors. To design a subsurface drainage system depth and spacing standards are required, but unfortunately these do not exist for Alberta. Even though drainage coefficients and spacings have been established for the humid areas of Canada none apply to southern and central Alberta.

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The objective of the study is to monitor the soil, groundwater and discharge of a number of field size dryland subsurface drainage projects, and use the data to establish drainage standards and adapt spacing and other equations to the Alberta dryland saline seep situation.

RESULTS

The following are the highlights of the research findings so far:

I. Soil Texture, Structure and Chemistry

The soils of the six drainage projects vary from thin overburdens of medium textured till to thick layers of coarse textured fluvial material, which were saturated with water and are under pressure. The salt and sodium levels varied from high in the former to low in the latter. Many of the six projects had soils with a solonetz character.

The Wobick saline seep had a resalinized solonetz soil. The overburden was an approximate 2.2 meter thick layer of clay loam till and lacustrine material (Appendix, Figure 2). The bottom half meter of this layer was saturated. Beneath this layer was less permeable, firm basal till, residual bedrock, shale and sandstone. The 2.1 meter deep tiles were located in the saturated layer, while the 1.5 meter deep tiles were above it, and the 2.7 meter deep tiles beneath it and in the bedrock. High salt and sodium levels, 20 mS/cm and 40 SAR, respectively, were present in the center of the saline seep and extended there to a considerable depth (4 meters).

In contrast to the Wobick drainage site the overburden at the Akitt site was thick (over 14 meters) and contained .5 - 12 meter of sandy fluvial material saturated with water under artesian pressure (Appendix, Figure 3). Some of the deeper tiles (2.1 and 2.7 meters) were installed in this layer. Overlying this layer and reaching to the surface was 2 - 6 meters of silty clay loam till, and in some places underlying this layer was firm basal till.

II. Rate of Desalinization

The soils of the drainage projects were resampled in 1983 and again in 1984. At the Wobick site between May, 1982 and June, 1984, the salt level in the top .3 meter decreased over the entire field and to even greater depths in many places of the field (see Table 1 A & B). Therefore, it was assumed that the average spring tile discharge rates of the last 2 years of this drainage project were equal or greater than its drainage coefficients and that the water table levels were equal or deeper than its critical water table depths. The soil samples were composites from three places and the analysis were carried out on extracts of the saturated paste.

III. Tile Discharge Quantity (and Quality)

The tile discharge measurements were used to determine the peak flow

TABLE 1 : Wobick - Soil Salinity (mS/cm) and its Change

Site	Depth	MAY 82	Change	JUNE 84	Change	
B4	.3	7.3	-0.9	6.4		
	.6	9.5	+1.0	10.5		
	.9	8.7	-0.5	9.2		
	1.2	7.9	-0.3	7.6		
	1.5	7.7	-2.3	5.4		
B7	.3	10.7	-4.2	6.5		
	.6	11.5	+0.9	12.4		
	.9	11.5	-0.7	10.8		
	1.2	11.3	-3.0	8.3		
	1.5	9.9	-0.8	9.1		
B9	.3	12.9	-7.9	5.0		
	.6	17.2	-7.7	9.5		
	.9	18.8	-6.7	12.1		
	1.2	14.5	-4.1	10.4		
	1.5	9.8	+0.8	10.6		
B12	.3	12.6	-5.7	6.9		
	.6	12.7	+0.5	13.2		
	.9	10.7	+2.2	12.9		
	1.2	10.7	-0.1	10.6		
	1.5	8.0	+2.8	10.8		
B14	.3	15.6	-5.8	9.2		
	.6	16.2	-0.5	15.6		
	.9	14.2	-0.9	13.3		
	1.2	13.1	-3.3	9.8		
	1.5	13.9	-4.5	9.4		

Site	Depth	MAY 82	Change	JUNE 84	Change	
B18	.3	13.7	-6.3	7.4		
	.6	16.1	-0.3	16.4		
	.9	12.1	+4.4	16.5		
	1.2	12.1	-0.6	11.5		
	1.5	14.4	-3.9	10.5		
B21	.3	17.7	-7.3	10.4		
	.6	15.2	+4.5	19.7		
	.9	13.2	+5.5	18.7		
	1.2	14.6	-0.3	14.3		
	1.5	17.1	-5.4	11.7		
B24	.3	15.0	-6.7	8.3		
	.6	14.1	+5.3	19.4		
	.9	12.7	+6.0	18.7		
	1.2	13.1	+0.4	13.5		
	1.5	14.0	-1.9	12.1		
B26	.3	15.1	-6.5	8.6		
	.6	15.8	+3.5	19.3		
	.9	13.2	+9.4	22.6		
	1.2	14.3	+4.3	18.6		
	1.5	16.5	-3.4	13.1		
B29	.3	24.1	-16.2	7.9		
	.6	23.9	-6.8	17.1		
	.9	22.9	+1.9	24.8		
	1.2	25.3	-7.1	18.32		
	1.5	23.9	-10.2	13.7		

TABLE 1B: Wobick -Soil Salinity (mS/cm) and its Change

Site	Depth	MAY 82	Change	JUNE 84	Change	
B31	.3	24.0	-15.5	8.5		
	.6	23.9	-11.1	12.8		
	.9	18.7	-15.6	24.3		
	1.2	17.7	-0.5	17.2		
	1.5	16.3	-3.6	12.7		
B35	.3	13.7	-1.4	6.4		
	.6	12.3	+3.2	15.5		
	.9	10.5	+3.4	13.9		
	1.2	8.4	+0.8	10.6		
	1.5	9.7	+0.8	10.5		
B38	.3	13.3	-6.8	6.5		
	.6	14.6	-2.1	12.5		
	.9	12.2	+4.6	16.8		
	1.2	12.4	+0.3	12.7		
	1.5	12.7	-0.7	12.0		
B41	.3	15.4	-9.7	5.7		
	.6	15.0	+0.1	15.1		
	.9	14.6	0	14.6		
	1.2	13.3	-0.7	12.6		
	1.5	12.7	+0.6	13.3		
B43	.3	12.4	-4.3	8.1		
	.6	16.7	+2.1	18.8		
	.9	14.2	-2.3	16.5		
	1.2	12.2	+1.8	14.0		
	1.5	14.9	-4.4	10.5		

Site	Depth	MAY 82	Change	JUNE 84	Change	
B46	.3	16.9	-7.2	9.7		
	.6	18.5	+0.1	18.6		
	.9	14.1	+11.0	25.1		
	1.2	14.0	+0.6	14.6		
	1.5	14.2	+2.5	16.7		
B48	.3	31.1	-16.8	13.3		
	.6	23.6	+2.6	26.2		
	.9	18.1	+1.1	19.2		
	1.2	20.4	-3.4	17.0		
	1.5	18.5	-8.4	10.1		

and the average spring flow. The peak discharge rates from individual lines ranged from as high as 335 L/day/m of drain to as low as 1 L/day/m tile (see Table 2). A 6-centimeter rain in August at the Racher site, caused the 335 L/day m of drain peak discharge 13 hours later. At Ostero's, the high discharge values resulted from one or two highly permeable fractures which were observed during installation. The lines, in some projects such as Keeler, Akitt and Ostero ran all of spring and consequently their average spring discharge was high.

TABLE 2: Peak and Average Spring Discharge from Tile Lines at Various Depths, 1983 (L/day/m)

Project Name	Peak Rate			Average Spring Rate		
	1.5 m	2.1 m	2.7 m	1.5 m	2.1 m	2.7 m
Wobick	3	4	4	1.5	3	1
Ostero	11	31		1.5	15	
Akitt	50	138	34	1.6	138	7
Racher	335	1		.1	.7	
Keeler	20	35	14	8	3	2

The effluent quality of the various projects varied greatly from as low as 1.9 mS/cm at the Akitt site to as high as 18.5 mS/cm at Racher's. In some projects the salt level of the effluent remained constant throughout the year, for example at Akitt's (Appendix, Figure 4), but on others it went up when the flow increased and down when the flow decreased, for example, at the Wobick outlet. Even though the outlet effluent quality at Wobick's varied during the summer, the effluent quality of the individual lines remained constant. The deeper lines here had considerably better quality water (8.0 mS/cm) than the shallow lines (33.0 mS/cm).

IV Drainage Coefficient

The drainage coefficient was determined from the average spring tile discharge divided by the tile spacing at the locations where the soils were desalinizing. The coefficient was dependent on the soil and the climate and therefore, was site specific. At the Wobick site where over the last 2 years the soil desalinized drainage coefficients were calculated and varied between .05 and .18 mm/day. These values are small compared to the coefficients used in humid regions (1.5 - 4.5 mm/d). Moreover, with the presence of artesian conditions, the coefficients were expected to be high. The accuracy of the above calculated values can only be verified, if during a period of increased precipitation, and rising water tables, the critical water table depth and the soil desalinization process are maintained.

V Hydraulic Conductivity

The hydraulic conductivities on five of the subsurface drainage research sites were measured using the auger hole and pumps in methods. The hydraulic conductivity values ranged form $.7 \times 10^{-1}$m/day to 4.5×10^{-1}m/day (see Table 3). These values were higher than the 1.8×10^{-2}m/day that Hendry obtained for large fractures in weathered tills. The hydraulic conductivities generally decreased with depth, for example at Wobick at the .9 - 1.8 meter depth the hydraulic conductivity was 4.5×10^{-1}m/day and at the 1.5 - 2.1 meter depth it was 1.6×10^{-1}m/day (Table 3). A correlation exist between the hydraulic conductivities obtained and the textures of the soil. The more sandy soils such as at Ostero and Akitt, produce the higher hydraulic conductivity values. A relationship could not be obtained between the hydraulic conductivity values and the peak tile discharges.

TABLE 3: Hydraulic Conductivities at Various Subsurface Drainage Sites, 1983 (L. Healy)

Sites	Depth (m) Tile	Depth (m) Sampling	Texture	P.M.	SAR	K (m/day)
Wobick	1.5	.9 - 1.8	SCL	Till-Lac	25	4.5×10^{-1}
		1.5 - 2.1	SCL	Till-Res	22	1.6×10^{-1}
Ostero	1.7	.7 - 1.5	SL-SCL	Till	16	4.1×10^{-1}
		1.0 - 2.0	SL-SCL	Res-Till	13	3.8×10^{-1}
Keeler	2.1	.9 - 2.1	C	Till	11.4	1.4×10^{-1}
		1.8 - 2.7	CL	Till	10.2	$.7 \times 10^{-1}$
Keeler	2.7	.9 - 2.4	CL	Till	14	1.1×10^{-1}
		2.4 - 3.0	CL	Till	11	3.0×10^{-1}

VI Spacing Equations

At the Wobick project, the water tables were generally steady. Hydraulic conductivity values for the soil around the 2.1 meter deep tiles were $K_1 = 2.5 \times 10^{-1}$m/day and $K_2 = 17.1 \times 10^{-1}$m/day, and the drainage coefficient was .18 mm/day. The equivalent depth of the 2.1 meter deep tiles was .5 meters, while the height of the water table above midpoint was minimal and assumed .01 meter. Using the modified Ellipse equation the spacing for the 2.1 m deep tiles was calculated to be

$$S = \sqrt{\frac{4\ K_1 h^2 + 8\ K_2 deh}{q}} = 19.4 \text{ meters}$$

The calculated spacing for the 1.5 m deep tiles was 7.4 meters. The calculated values varied considerably when some of the input parameters such as: drainage coefficient and height of water table above midpoint, were changed only slightly. For that reason spacings might have to be determined from the water table configuration data of these research projects collected in the field.

VII Tile Influence on Water Table (Shape and Depression)

The water table configuration and the effect of the tiles on it varied from site to site. In a few projects, the water table remained temporarily or permanently above the tiles. Some of these water tables showed distinct depressions caused by the tiles. On two projects the water table remained approximately at tile depth and fluctuated little. On another site the water table remained below the drain tile during the last few years.

At the Keeler drainage site during 1983 and 1984, the water table was above the tiles. Distinct cones of depression were obtained by the 2.7 and 2.1 meter deep tiles. Above the four 2.7 meter deep tiles the combined cone of depression was .8 meter deep and over 150 meters wide (Appendix, Figure 5). The cones of depression also overlapped above the 2.1 meter deep tiles and combined were .6 meter deep and over 60 meters wide. The 1.5 meter deep tiles were installed at the existing water table level and had little effect. The water table recession was .6, .3 and .05 meter, above the 2.7, 2.1 and 1.5 meters deep tiles, respectively, during the period from February 21 to July 31, 1984.

At the Akitt site, a saturated, thick layer of sand directly below the tiles exercised a strong upward pressure on the water table. In some places, the water table remained above the tiles, even though the drains were discharging as much as 138 L/day/m tile. The water table recession near these lines was minor. On the other hand, at line B, where the saturated layer was smaller and possibly less pressurized a distinct zone of depression was present, which was .4 meter deep and extended about 10 meters away from each tile (Appendix, Figure 6). Here the impression on the water table was maintained even when through natural drainage the water table dropped below the tiles.

At the Wobick drainage site the water tables fluctuated only slightly and were in most places maintained approximately at the 1.5 and 2.1 meter depth of the tiles (Appendix, Figure 7). The 2.7 meter deep tiles, installed in the bedrock, lowered the water table to the top of the residual bedrock. The water table was nearly flat and did not show any distinct cones of depression.

The hydrographs of the various wells show that the water tables were high at the time the tiles were installed. Since that time levels have dropped on all projects, even though during the spring there are sizeable, temporary rises (Appendix, Figure 8). At the Wobick site the rises in the spring water table level was considerably less compared to before and to other projects.

VIII Critical Water Table Depth and Recession Rate

A water table maintained at the critical depth and recession rate permitted desalinization. The critical values were determined quickest at the upper edge of expanding, non-artesian saline seeps. At the Kientopp saline seep L 1-5 (Appendix, Figure 9) 6 places were sampled to a depth of 2.4 meters and water table wells installed. Soil analysis showed an abrupt change in the surface salinity between sites L3 and L4, indicating the upper edge of the saline seep and the location of critical values. The spring water table depth and recession rate here were 1.5 meter and .03 cm/day, respectively. At the Elmspring Colony L11 - 15B site, the critical water table depth and recession rate were located at well site L13 and were at least 2.4 meters and .06 m/day, respectively (Appendix, Figure 10). The soil in this project was fine and moderately fine textured. At another Elmspring Colony site the critical water table depth and recession rate were 1.7 meters and .05 m/day, respectively. The soil here was moderately fine. At the Norris project the critical water table depth and recession rate were found between well sites L40 and L41 and were 2.4 meters and .04 cm/day, respectively (Appendix, Figure 11). The depth was calculated from the bottom of the grass root zone on down. The soil at these sites was moderately fine textured.

CONCLUSIONS

A large amount of data has been collected on the six research drainage sites. Sizeable amounts of water were discharged by the systems and the soil in some projects started to desalinize. During the last two years, precipitation in southern Alberta has been below normal. Before the effectiveness of the drainage systems and the accuracy of the various parameters can be verified, one or two years of high precipitation are needed.

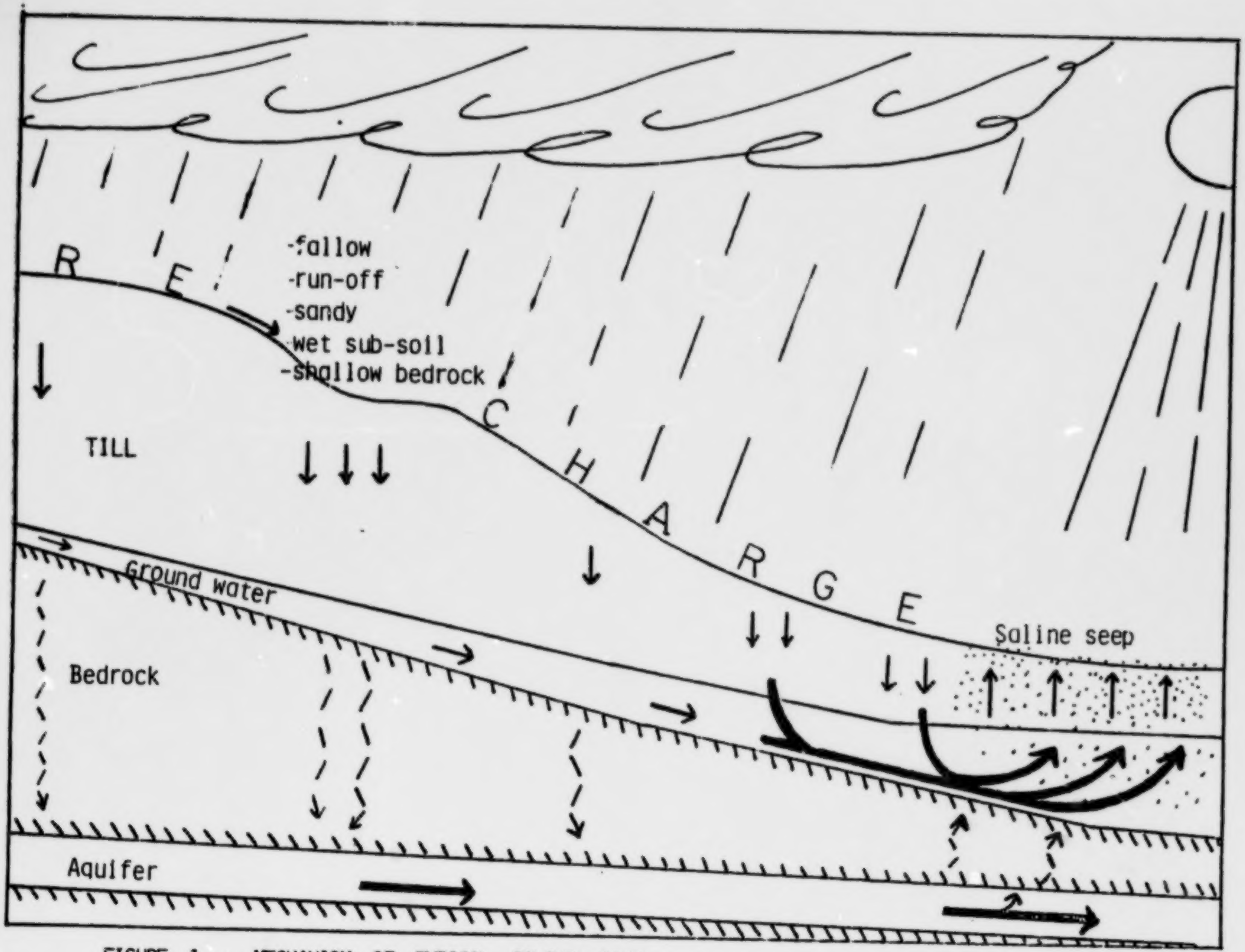
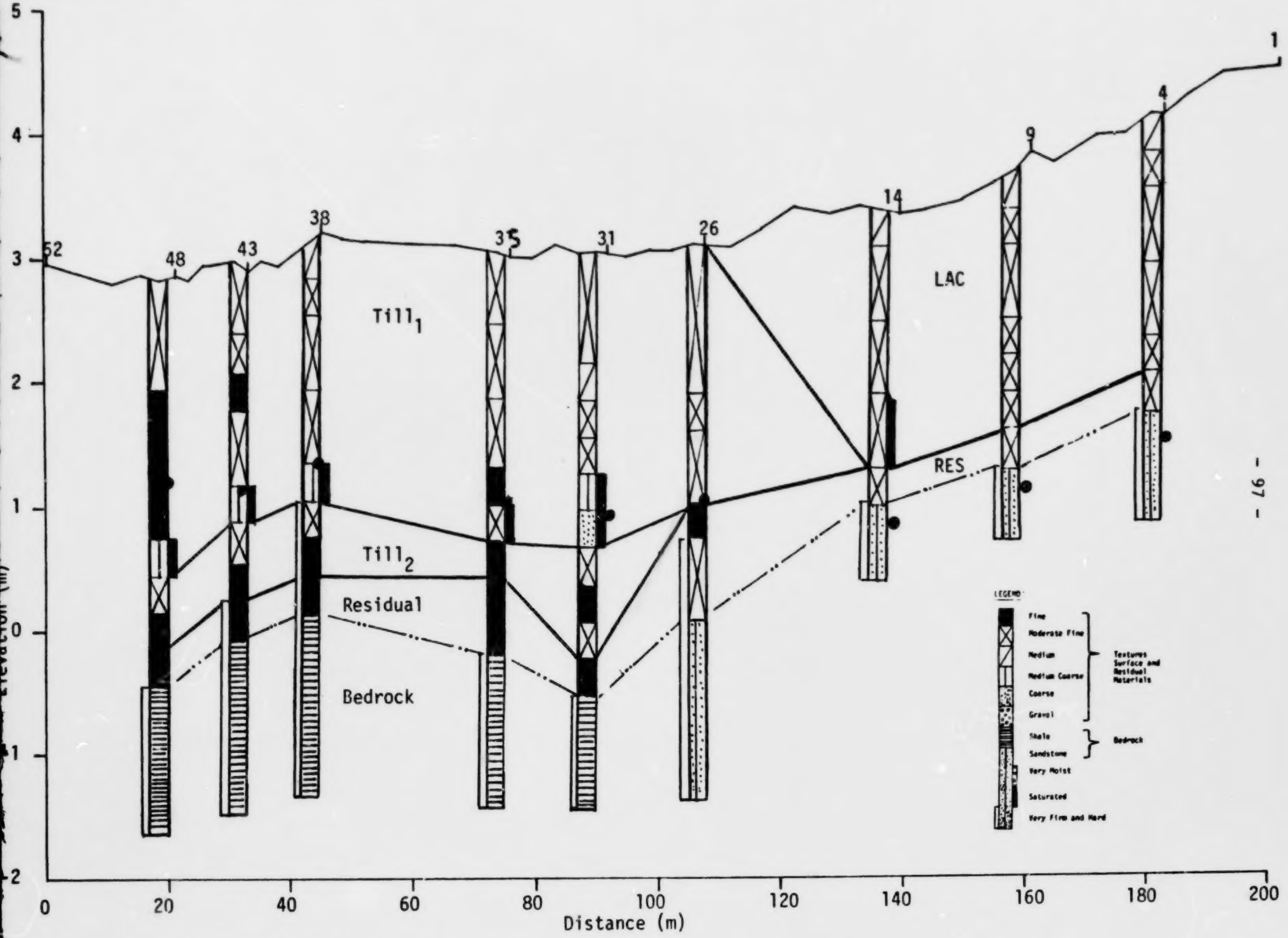

R E C H A R G E
-fallow
-run-off
-sandy
-wet sub-soil
-shallow bedrock
TILL
Ground water
Bedrock
Aquifer
Saline seep

FIGURE 1 : MECHANISM OF TYPICAL SALINE SEEP


Elevation (m)
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4
3
2
1
0
-1
-2
Distance (m)
0
20
40
60
80
100
120
140
160
180
200
52
48
43
38
35
31
26
14
9
4
1
Till$_1$
Till$_2$
Residual
Bedrock
LAC
RES
LEGEND
Fine
Moderate Fine
Medium
Medium Coarse
Coarse
Gravel
Textures Surface and Residual Materials
Shale
Sandstone
Bedrock
Very Moist
Saturated
Very Firm and Hard

Figure 2. Soil profile, Line B, Wobick

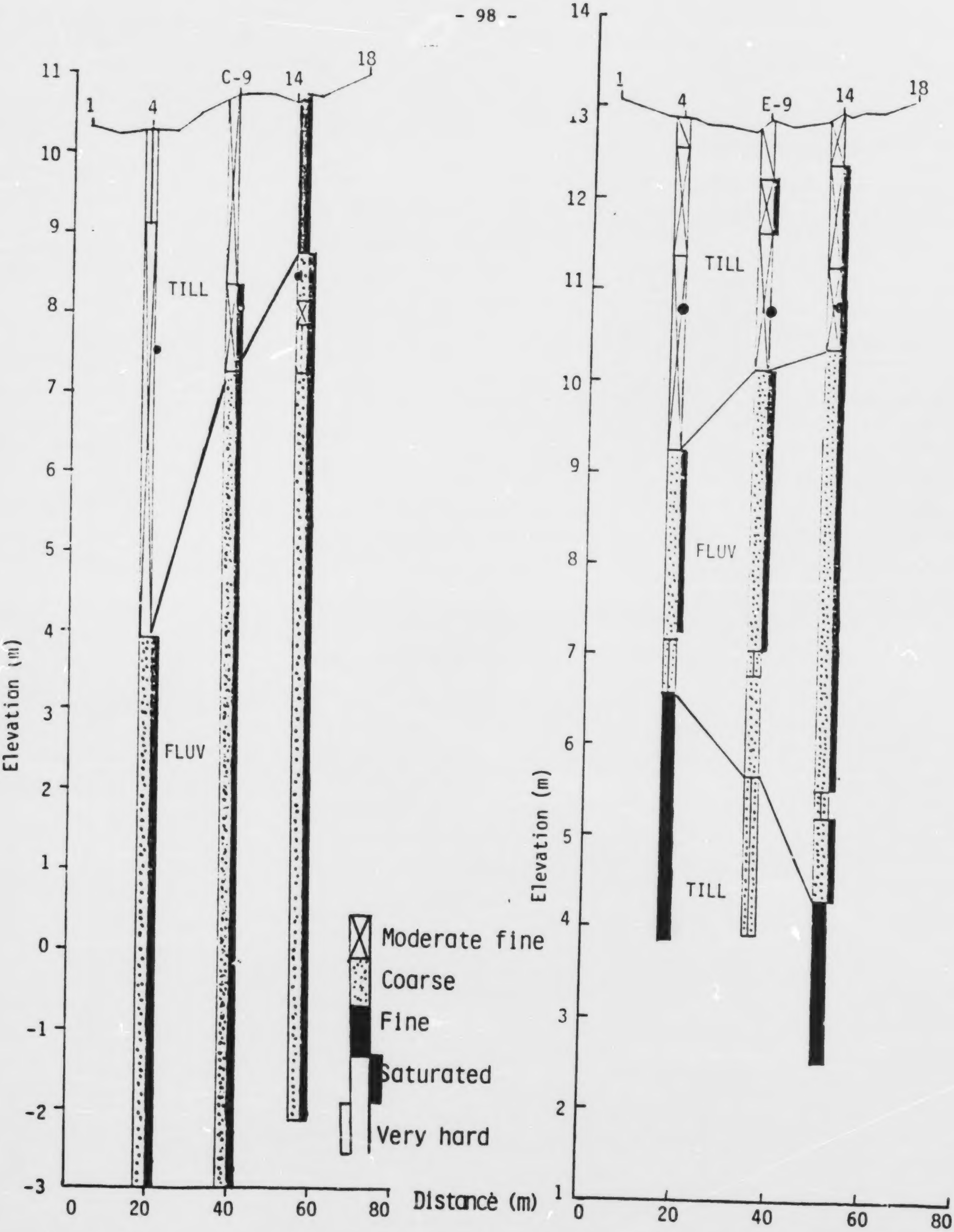

Elevation (m)
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
1
4
C-9
14
18
TILL
FLUV
0
20
40
60
80
Distance (m)
Moderate fine
Coarse
Fine
Saturated
Very hard
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
4
E-9
14
18
TILL
FLUV
TILL
Elevation (m)
0
20
40
60
80

FIGURE 3 : SOIL PROFILE OF THE LINES C AND E , AKITT.

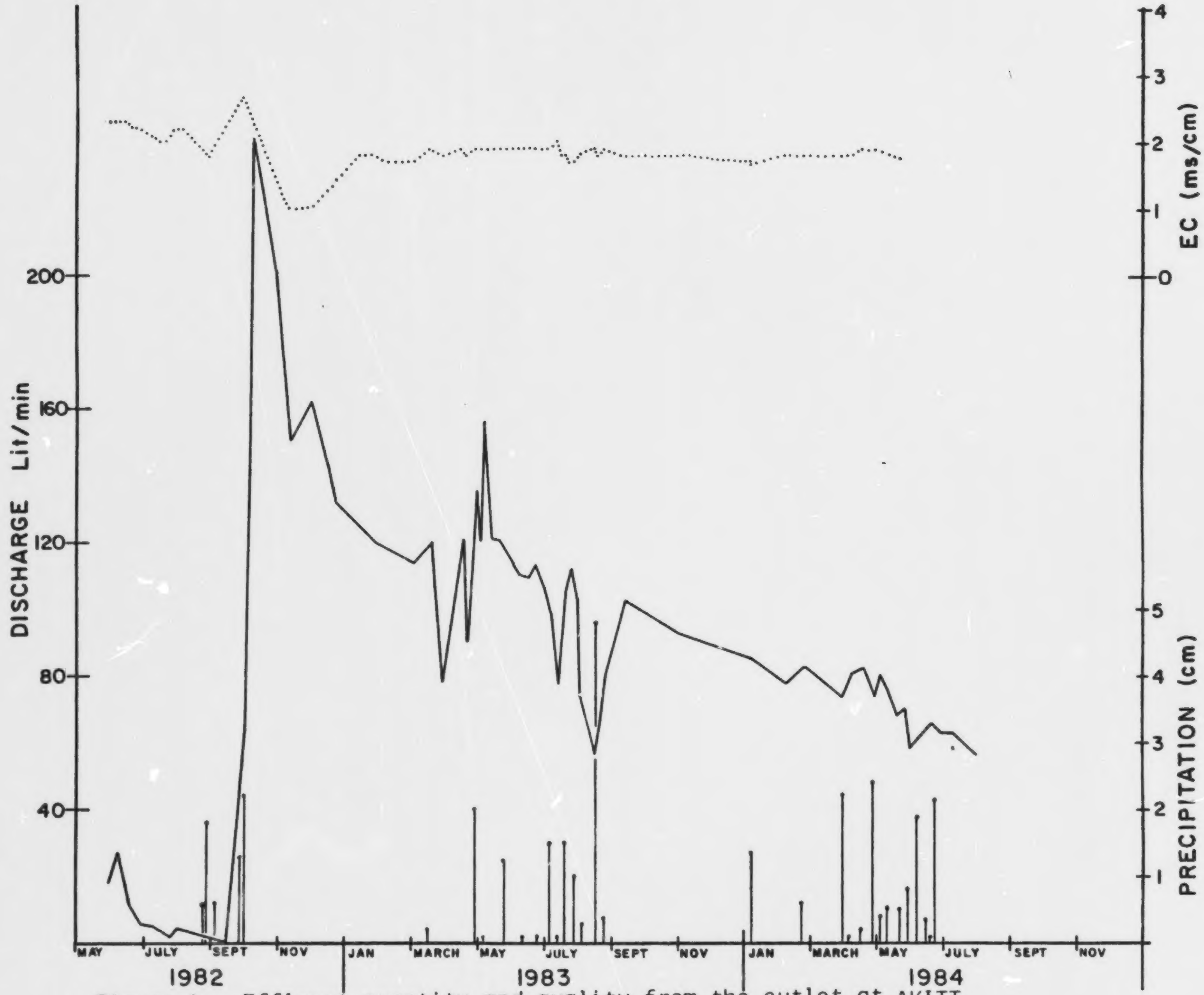


Figure 4. Effluent quantity and quality from the outlet at AKITT

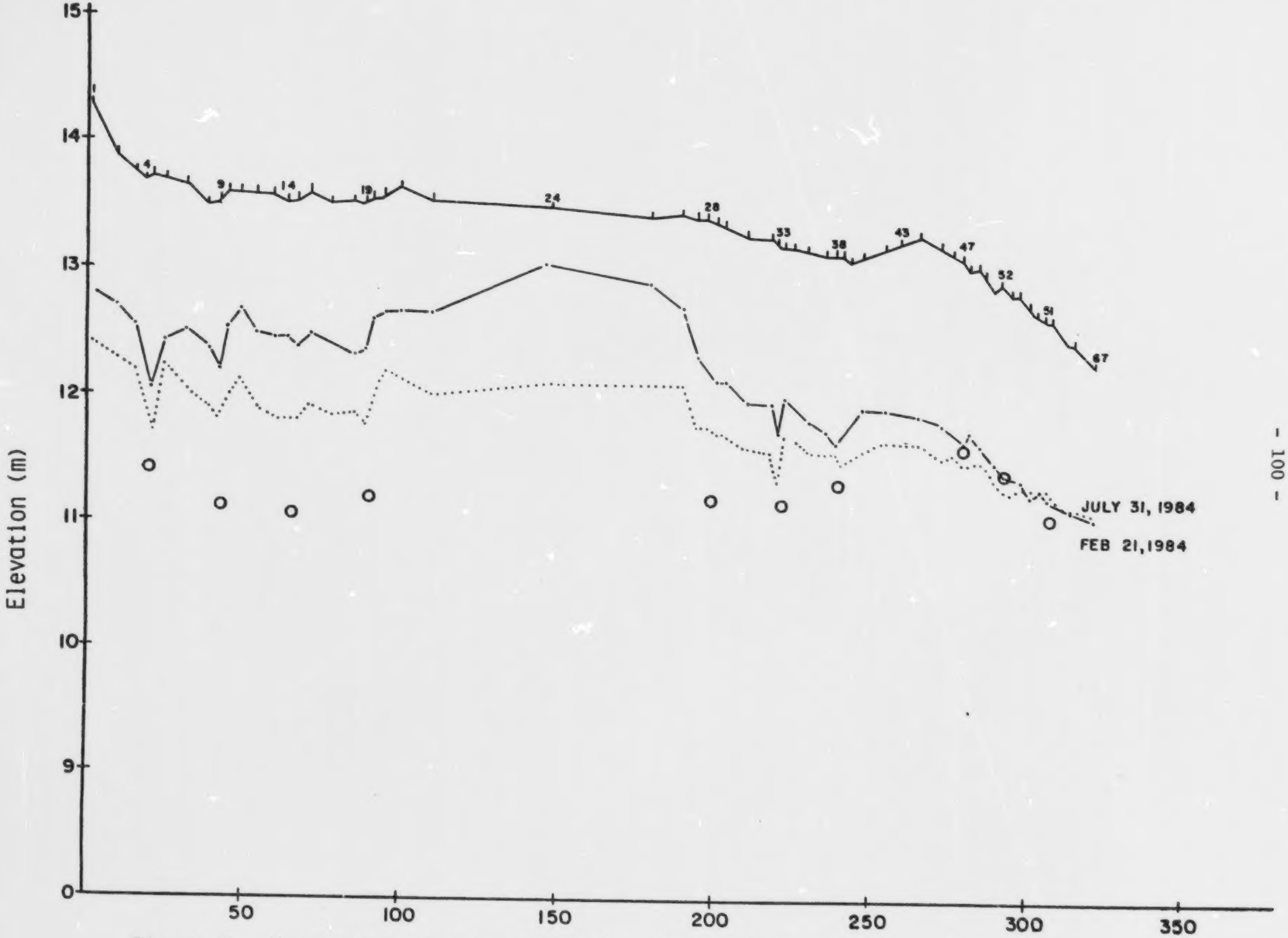


Figure 5. Water table levels, Line A, Keeler, 1984

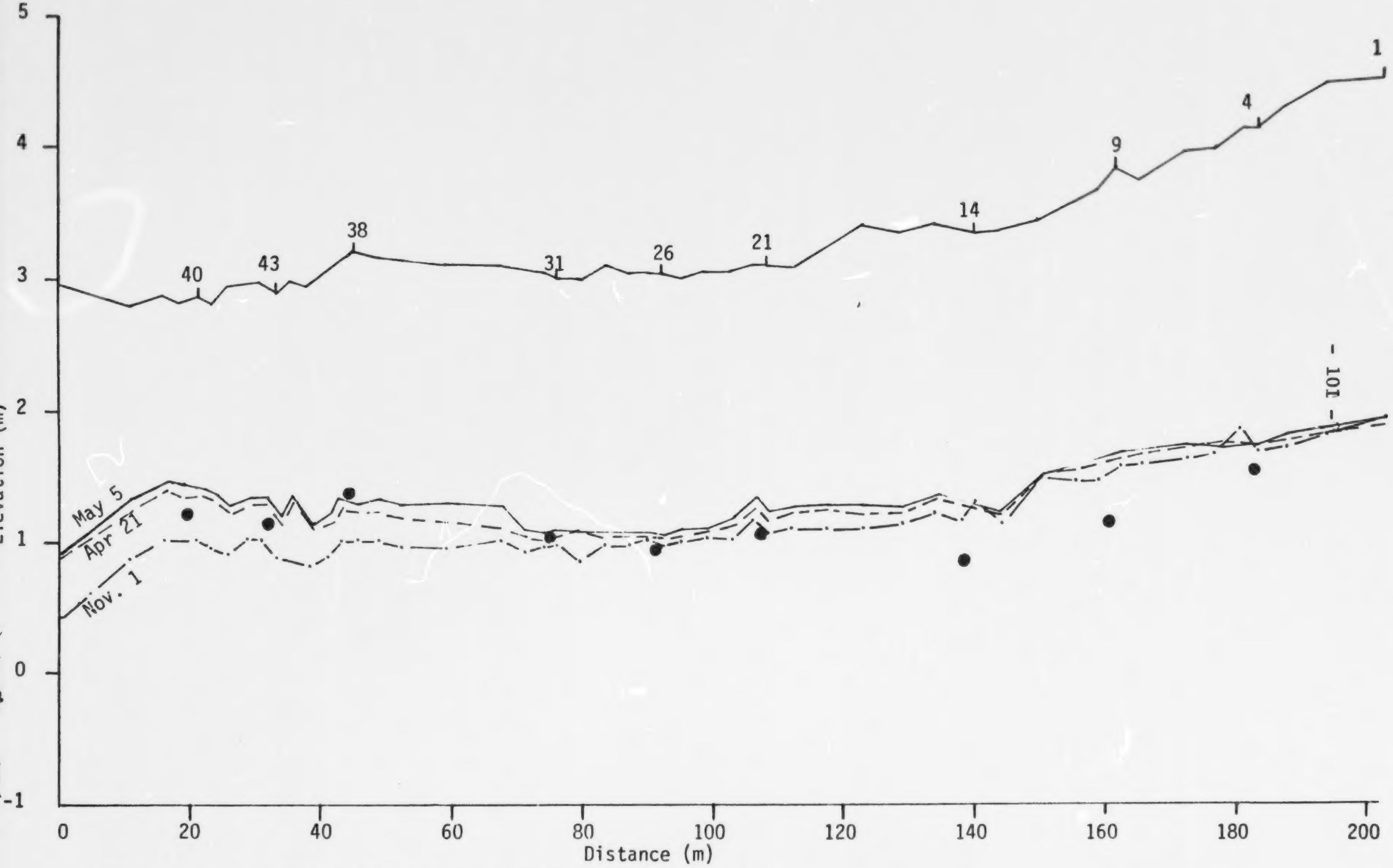
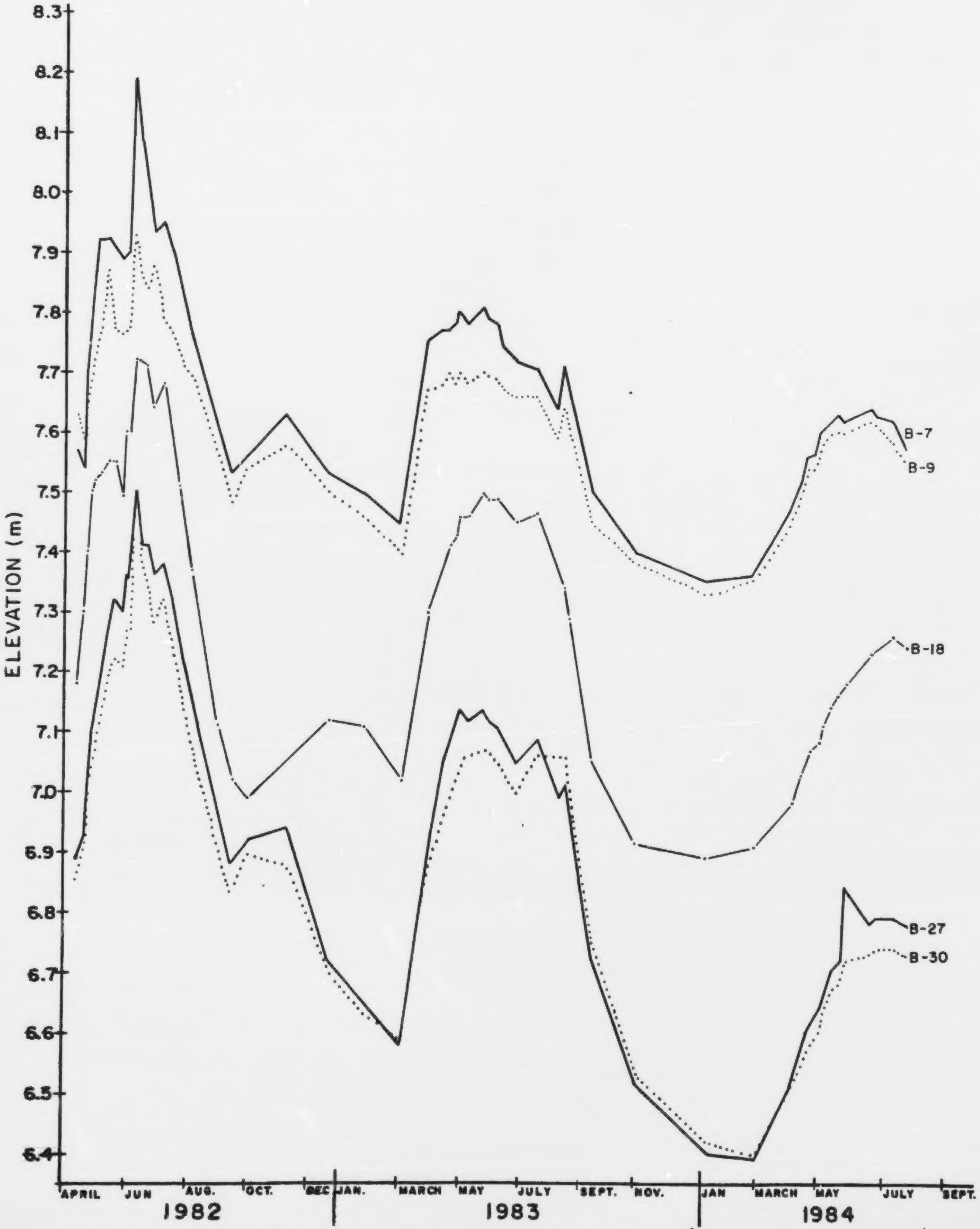


Figure 7. Water table level, Line B, Wobick, 1983

Figure 8. Hydrograph of Water-table levels, Line B, Racher



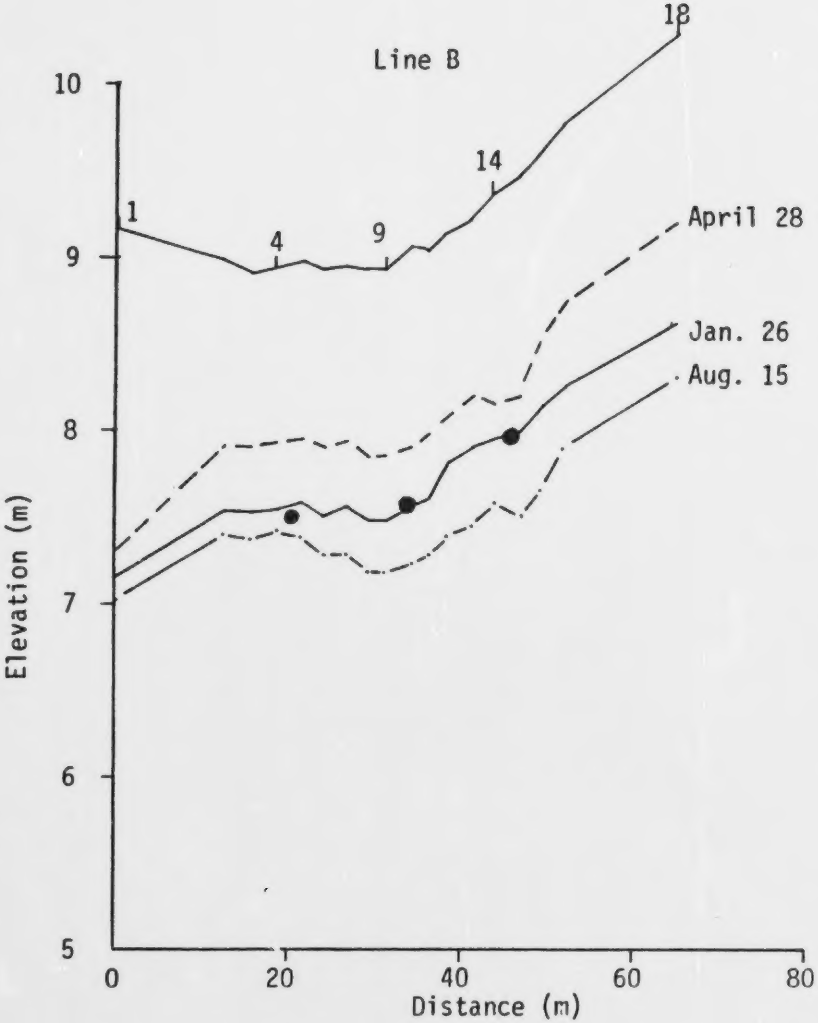


Figure 6. Water table levels, Line B.
AKITT, 1983

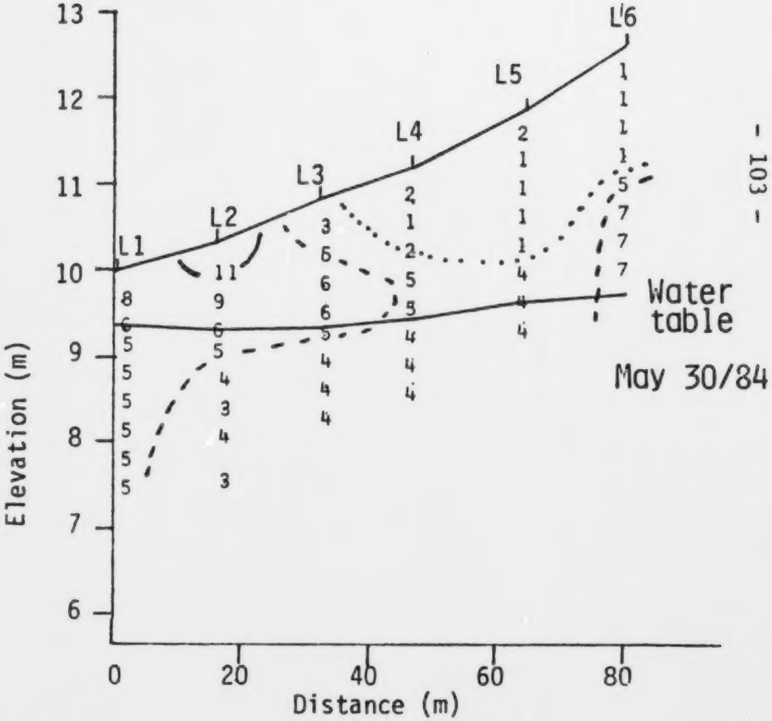


Figure 9. Soil electrical conductivity (mS/cm) Sept. 1983
Kientopp

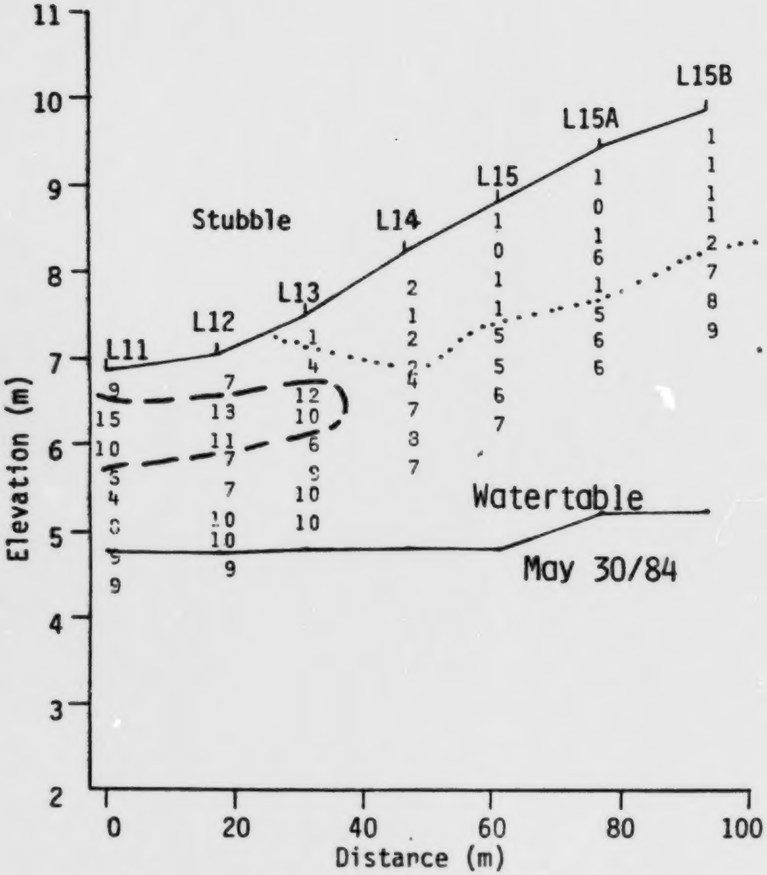


Figure 10. Soil Electrical Conductivity (mS/cm) Sept. 1983, Elmspring Colony

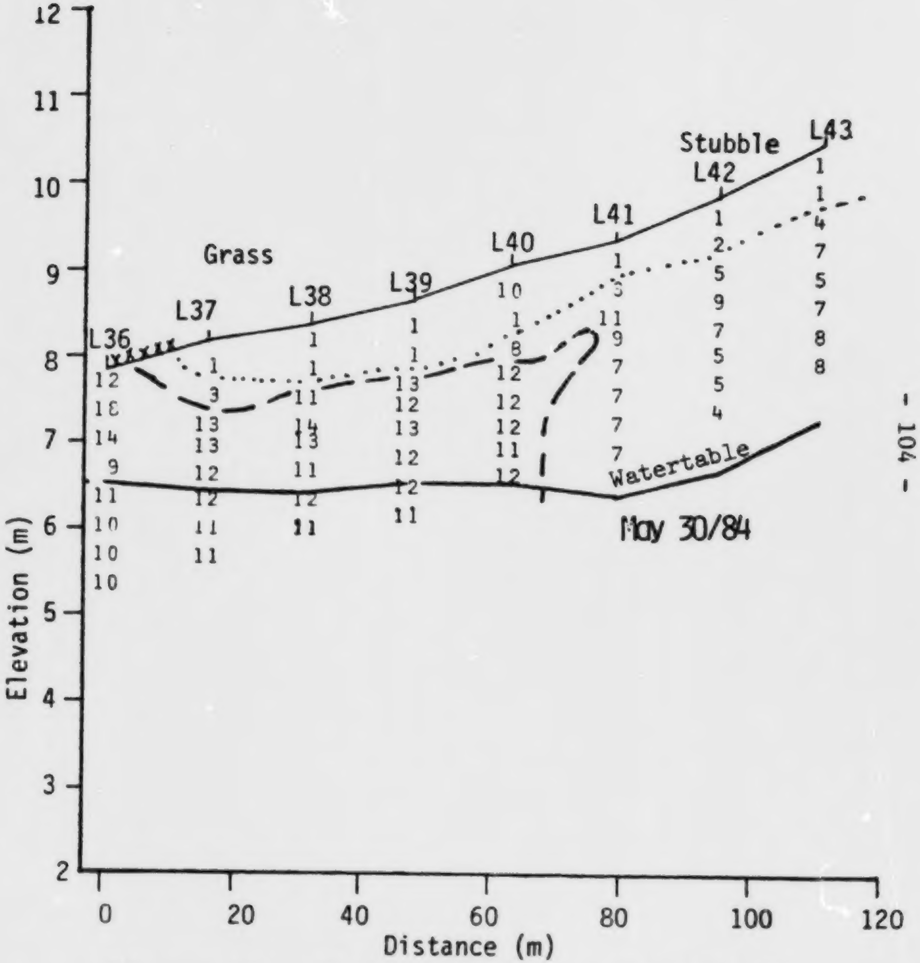


Figure 11. Soil Electrical Conductivity (mS/cm) Sept. 1983, Norris

EFFECT OF AGRICULTURAL LAND DRAINAGE ON SOIL CHARACTERISTICS AND CROP GROWTH

R.A. Bertrand[1], M.G. Driehuyzen, D. Pedersen

1.0 INTRODUCTION

The Lower Fraser Valley is located in the southwest corner of the British Columbia mainland. Although the area contains only 3% of the provinces farmland it accounts for approximately 50% of the value of agricultural production (7). The major crops include grass and silage corn for dairy and beef animals, small fruits, and a broad range of fresh and processed vegetables. The area is one of the main dairy producing regions in the country and it accounts for about 95% of the raspberries produced in Canada.

The main climate characteristics of the Fraser Valley are mild winters and warm, but not hot summers. The area has one of the longest freeze free periods in Canada, exceeding 200 days in some locations. Due to the frequent passage of low pressure systems during the winter months, precipitation is heavy and often intense. On average winter precipitation at the site of the project to be reported on in this paper is 750 mm while potential evapotranspiration is 60 mm (1). Since the precipitation falls as rain on unfrozen soils, this results in a soil saturation and ponding problem on level lands and an erosion hazard on sloping lands. Figure 1 illustrates the precipitation and P.E.T. difference in the Fraser Valley.

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[1] B.C. Ministry of Agriculture and Food, Surrey, B.C.

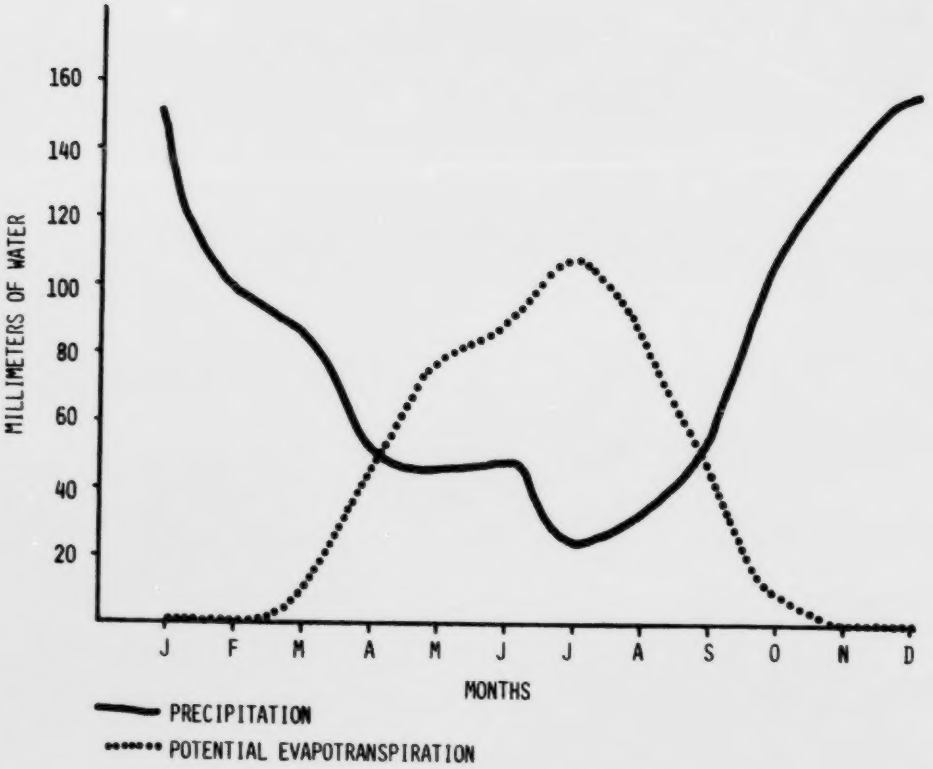

Figure 1: Average precipitation and potential evapotranspiration in the western end of the Fraser Valley.

The dominant soils in the Fraser Valley are lowland soils of fluvial, deltaic, organic, and marine origin and uplands soils of eolion, glacio fluvial, glacio marine, and glacial till origin (3). Approximately 76,000 hectares are gleysols and organics which have limitations for agriculture due to excess wetness (5) and over 50,000 hectares have slopes in excess of 3% resulting a water erosion hazard (6).

Excess water resulting in poorly drained soils and soils subject to erosion, is the main soil related limitation to agriculture in the Fraser Valley. Because of the significance of this problem to agriculture in B.C. the Soils Branch of the B.C. Ministry of Agriculture and Food initiated a research project in 1981 on a lowland soil in the Fraser River delta at the western end of the valley.

The objective was to determine the effects of drainage and subirrigation on soil characteristics and crop growth.

2.0 METHODS AND MATERIALS

The research site is located on Transport Canada property at Boundary Bay airport. The soil is a Humic Luvic Gleysol with surface textures ranging from silty clay loam to silt loam and the subsurface is mostly silty clay loam. The soil (Ladner series) is moderately poorly to poorly drained and moderately to slowly pervious (3).

Site preparation began in 1981 with installation of a drain and ditch system. The soil was broken in the spring of 1982 and the entire site was seeded to barley to allow one year for the site to stabilize. A pump was installed in the fall of 1982, and 1983 was the first year that the four test crops - grass, corn, potatoes, and strawberries - were planted. The project consists of four water management regimes (Figure 2), described as follows:

Regime A - drainage at all times.

Regime B - drainage during periods of excess precipitation and subirrigation to a height of 60 cm below ground level during periods of moisture deficit.

Regime C - drainage and subirrigation to a height of 30 cm below ground level during periods of moisture deficit.

Regime D - control; no drainage, no subirrigation.

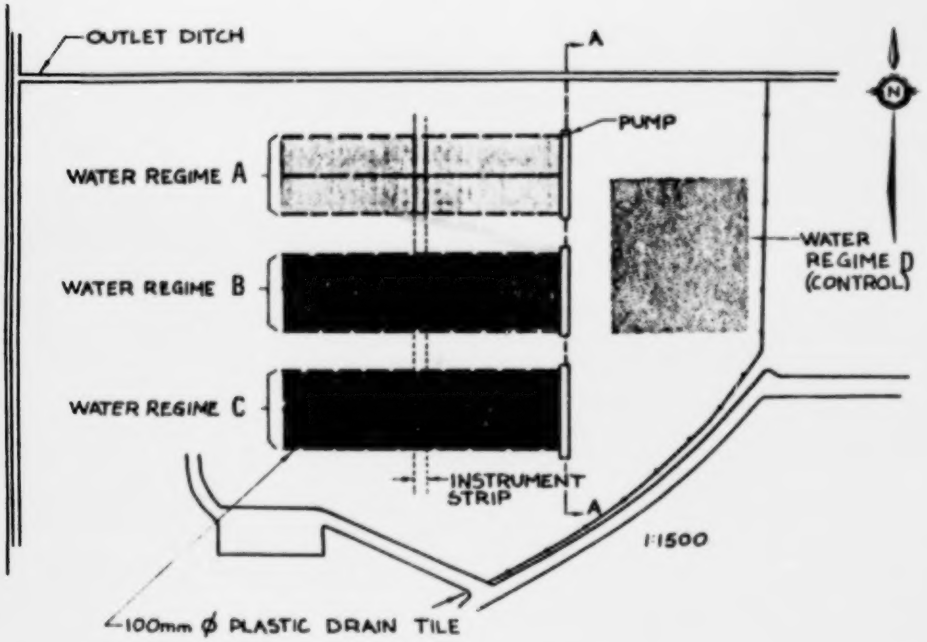
OUTLET DITCH
A
PUMP
WATER REGIME A
WATER REGIME B
WATER REGIME C
WATER REGIME D (CONTROL)
N
INSTRUMENT STRIP
A
1:1500
100mm ϕ PLASTIC DRAIN TILE

Figure 2: Boundary Bay Project site

Soil and climate parameters have been measured on a regular basis and include:

a) groundwater table using Stevens water level recorders which provide a continuous daily record of water table fluctuations.
b) soil moisture at various depths to 75 cm.
c) precipitation.
d) net radiation.
e) air temperature.
f) earth worm content.

Although all four crops were planted in 1983 data comparing drained to undrained sites was collected only for potatoes. Problems were overcome in 1984 and a complete set of data on crop performance was collected.

Land preparation and planting of crops was governed, in addition to agronomic criteria, by trafficability and workability of the soil. From studies done in the Fraser Valley it has been determined that the water table must be at least 50 cm below the soil surface before the soil is trafficable (2). Because of this criterion, land preparation, fertilization, weed control practices, and planting on the undrained plots was delayed considerably compared to the drained site.

Subirrigation water was introduced into the drainlines in Regimes B and C and held at depths of 30 cm and 60 cm below the ground surface, respectively, when 50% of the available water storage capacity was depleted. After crop growth was completed the water table was allowed to fall in these regimes and the soils were drained during the winter months.

3.0 RESULTS AND DISCUSSION

3.1 SOIL

3.1.1 WATER TABLE

Water table records have been collected since the fall of 1982. The following figures provide a comparison of the drained (Regime A) and undrained (Regime D) soils for 1983 and the first 9 months of 1984. In the undrained soil the water table remained at, or near the surface from late fall, through the winter months, and well into spring. The area was often flooded. In the drained plot numerous, very sharp peaks are evident on the graph of the water table levels. These peaks correspond to periods of heavy rainfall. However, the excess water was rapidly removed from the surface soil layer and on average the

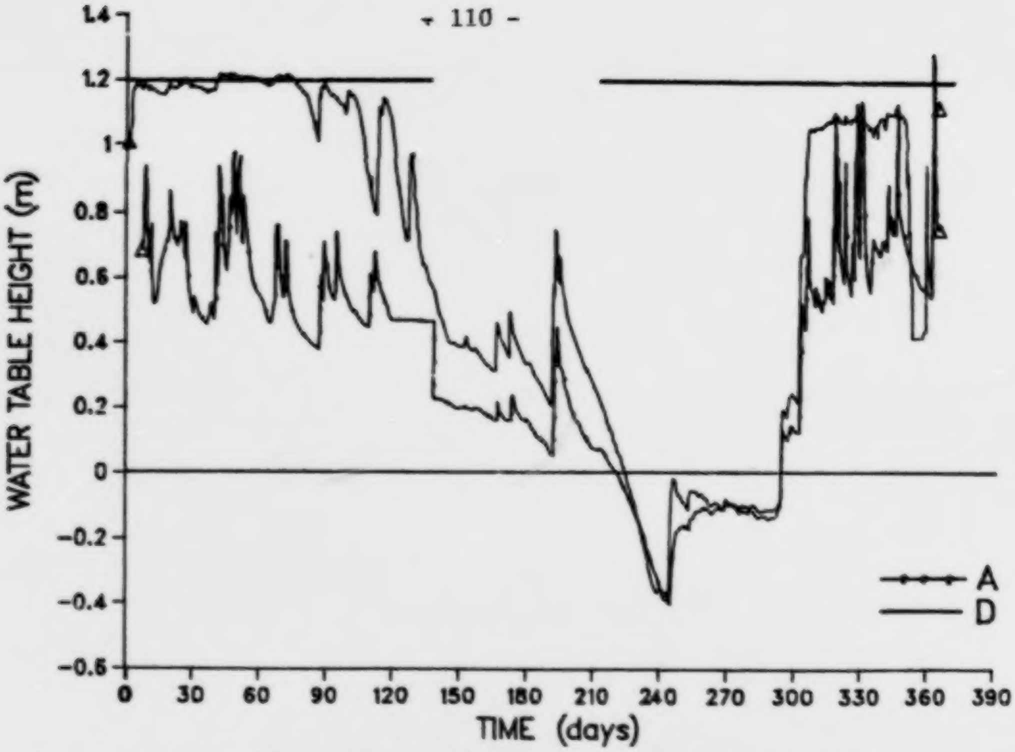

Figure 3: Water table in drained (A) and undrained (D) areas in 1983

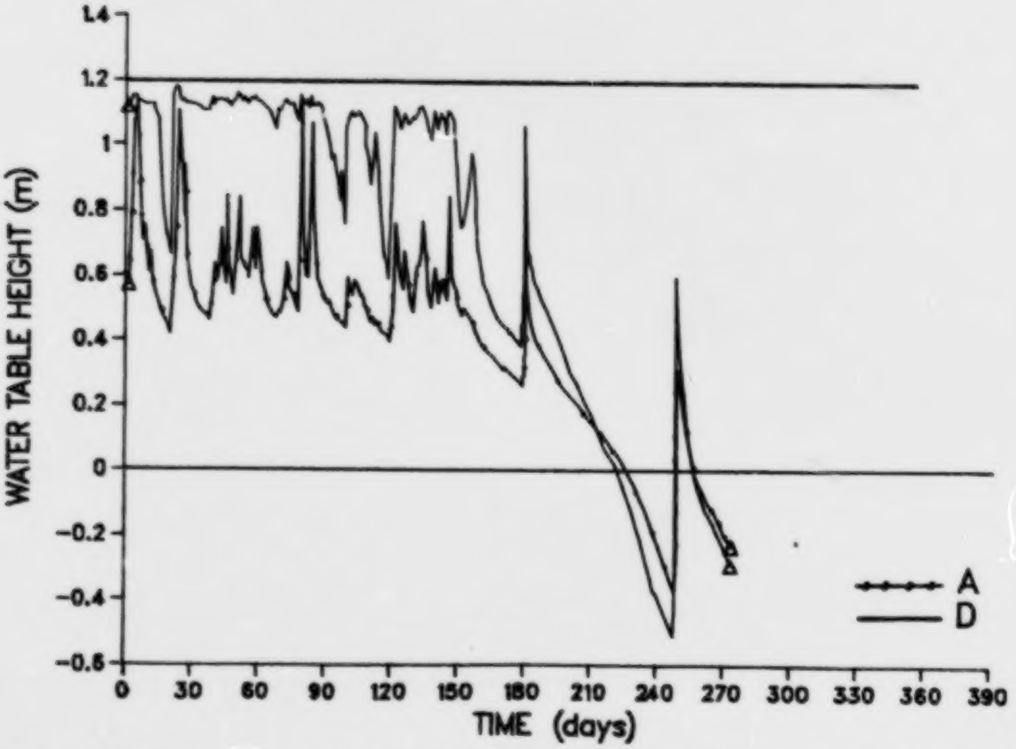

Figure 4: Water table in drained (A) and undrained (D) areas in 1984.

water table was generally below the 50 cm level.

Removal of excess water is most critical during the spring of the year. To produce top yields it is important to be able to work the soil early and prepare a good seedbed without excess compaction and degradation of soil structure. Excess water prevents field access, and, therefore, reduces the number of opportunities to work the land and to sow crops. A day when the water table is sufficiently low (50 cm or more below the ground surface) to allow traffic onto the field and the soil to be worked, is defined as an opportunity day. In 1983 and 1984 there were 78 and 134 more opportunity days respectively on the drained land as compared to the undrained area (Table 1).

Subirrigation in 1983 may have reduced opportunity days on these sites in 1984. Internal drainage may have been disrupted due to saturation of the subsoil in the 1983 growing season. Further observations are required to determine the importance of this reduction in opportunity days and the degree to which this may offset the potential benefits from subirrigation.

Table 1: Effect of drainage and subirrigation on opportunity days.

	OPPORTUNITY DAYS (January 1 to May 30)	
	1983	1984
Undrained	19	28
Drained	97	162
Drained/Medium Subirrigation	83+*	108
Drained/High Subirrigation	89+*	99

* actual number of opportunity days was higher than the values reported. Equipment malfunction prevented determining the actual number.

3.1.2 EARTHWORM POPULATION

Earthworms are thought to be a very important factor in increasing the hydraulic conductivity of soils in coastal B.C. Worm channels provide conduits for water to move through the soil to the water table. Due to extended saturation of the soil in the undrained plots, worms are not able to survive and thus cannot facilitate soil drainage when the water table begins to fall in the spring. Measurement of earthworm population has shown a very large benefit due to drainage (Table 2).

Table 2: Effect of drainage on earthworm populations (4).

	EARTHWORMS (g m^{-2})	
	1983	1984
Undrained	1.6	0.22
Drained	35.6	19.4

3.1.3 EFFECT OF SUBIRRIGATION ON SOIL PHYSICAL CONDITION

Subirrigation has been used for many years in the Fraser Valley on certain sandy soils, to provide supplemental water during summer months. This is accomplished by raising the water level of border ditches. However, the subsoil at the Boundary Bay project site is silty clay loam to clay loam. An objective of the project is to determine the feasibility of providing supplemental irrigation in heavy textured soils by using the drainage system. Figure 5 compares the water table levels in the drained plot to the levels in the site that is drained in the winter and subirrigated to a depth of 30 cm below the soil surface during periods of moisture deficit.

The water table level in the subirrigated plot was measured midway between drain lines. In 1983, and 1984, the water table rose very rapidly after water was introduced into the system. This rapid response was not expected and provided some initial encouragement relative to the feasibility of using the system for irrigation.

As indicated by the data on opportunity days (Table 1), the subirrigation treatment seems, however, to have affected internal soil drainage. Figure 6 shows the difference between the water table peaks in the drained as compared to the subirrigated site. The water table consistantly rose higher in the subirrigated treatment during precipitation events.

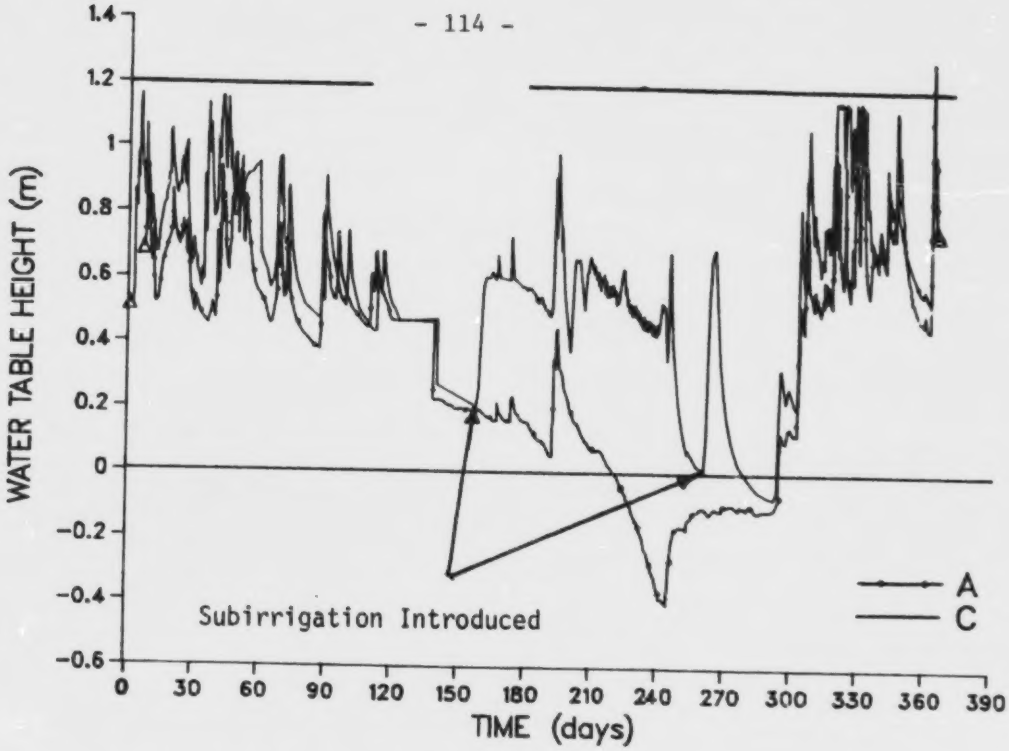

Figure 5: Water table in drained (A) site and in area subirrigated to a depth of 30 cm below the soil surface (C); in 1983.

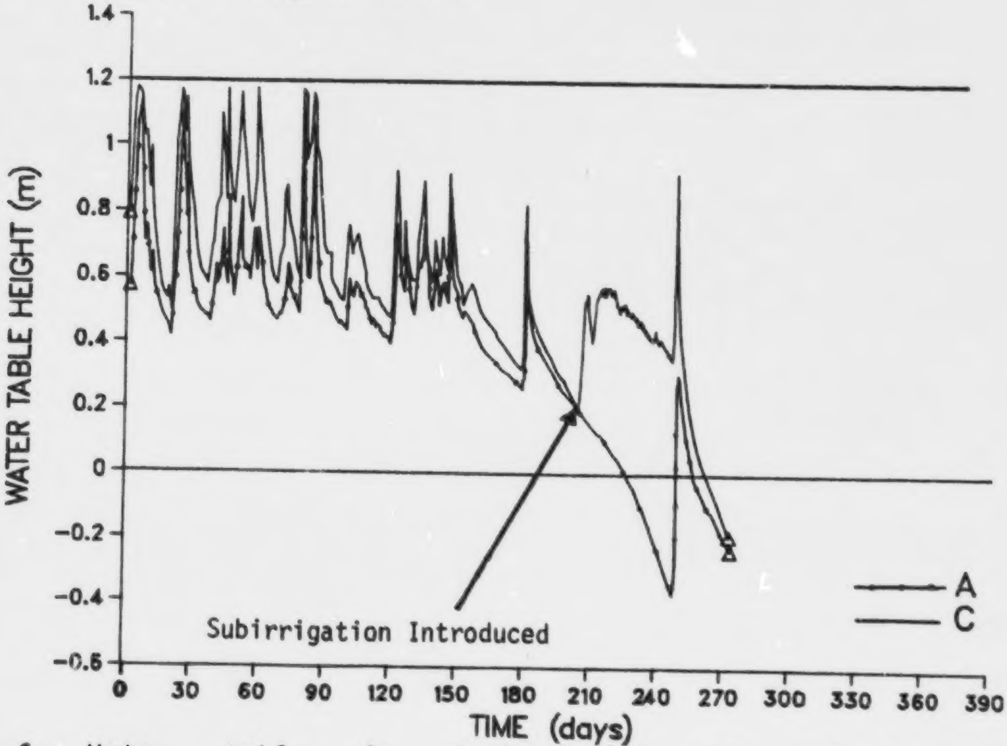

Figure 6: Water table in drained (A) site and in area subirrigated to a depth of 30 cm below the soil surface (C); in 1984.

3.2 CROP PRODUCTION

3.2.1 STRAWBERRIES

Strawberries were chosen as one of the test crops because they are a major crop in the Fraser Valley and the plants are sensitive to winter injury due to excess water. The objective was to determine whether sufficient water control could be established on a poorly drained, relatively heavy textured soil to prevent injury from excess soil water.

Table 3 compares 1984 yields of strawberries on the undrained site to yields on the drained site. The average yield in the Fraser Valley for 1984 is also indicated. Without drainage the yield was 1.5 $t.ha^{-1}$ compared to 5.2 $t.ha^{-1}$ where the soil was drained. Yields on the drained site compared favourably to other areas of the Fraser Valley which are generally considered to be superior for strawberry production.

The berries were harvested before subirrigation was introduced, so there was no effect in 1984. Subirrigation during the previous growing season had no affect on 1984 yields.

A dominant cause of low yield and survial of strawberries on the undrained site was the inability to get onto the land to control weed infestations. Lack of opportunity days to undertake necessary cultural activities resulted in a very rapid decline of the stand.

Table 3: Effect of drainage on strawberry yield in 1984.

	FRESH STRAWBERRY YIELD (t.ha^{-1})
Undrained	1.5
Drained	5.2
Average Fraser Valley Production	3.4 TO 4.5

3.2.2 POTATOES

Potatoes were selected as a test crop because they are a major crop in the Delta area of the Fraser Valley and production and harvesting problems are common on poorly drained soils which have a significant clay content.

The objective was to determine the effect of complete water control on production and harvestability of potatoes on a relatively heavy textured soil.

Total potato tuber production in 1983 was increased by 18 t.ha^{-1} due to drainage (Table 4). However, in 1984 total tuber yield was 5 t.ha^{-1} lower on the drained site as compared to the undrained area. These differences in the effect of drainage on yield were probably due to variations in precipitation patterns between the two years. In 1983 opportunity days in the spring on the drained site were sufficient to allow the crop to be planted on May 6. The undrained land could not be planted to potatoes until May 25. The growing season was characterized by above normal precipitation which prevented a significant soil moisture deficit from occurring and resulted in very high yields. Delayed planting of the potatoes on the undrained site resulted in a lower total yield.

In 1984, above normal spring rainfall delayed field operations to the extent that planting dates for the drained and undrained sites were June 1 and June 22, respectively. This delay of almost a month compared to 1983, resulted in significantly lower yields than in the previous year. (A different potato variety may also have contributed to lower yield.) In addition, precipitation during July and early August was much below normal, which further lowered yields. It would appear that soil moisture conditions on both the undrained and subirrigated sites were more favourable than on the drained area, and resulted in yield increases of 5 to 7 $t.ha^{-1}$.

Further evidence of this more favourable moisture condition is shown in Table 5. In 1984, marketable tubers were separated from cull tubers. The amount of culls was greatest on the drained site that received no subirrigation (25%), and decreased to 11% on the undrained area, and to 12% where the water table was raised to 30 cm below the soil surface during the growing season. The greater cull rate was mainly due to misshapen potatoes which is evidence of moisture deficit during critical portions of the tuber forming period.

Further investigation is required to obtain a better measure of the effect of drainage and subirrigation on potato production.

Table 4: Effect of drainage and subirrigation on total yield of potato tubers.

	POTATO YIELD ($t.ha^{-1}$)	
	1983	1984
Undrained	49	29a
Drained	67	24b
Drained/Medium Subirrigation	60	29a
Drained/High Subirrigation	59	31a

Table 5: Effect of drainage and subirrigation on marketable yield of potato tubers.

	POTATO YIELD ($t.ha^{-1}$)		
	TOTAL	MARKETABLE	% CULLS
Undrained	29	26	11
Drained	24	18	25
Drained/Medium Subirrigation	29	23	19
Drained/High Subirrigation	31	28	12

3.2.3 GRASS

Dairy farming is the dominant agricultural land use in the Fraser Valley. Forage grasses are one of the main feed sources for dairy animals. The most productive species adapted to the coastal marine climate have some sensitivity to excess wetness. Also, top yields are achieved by frequent clipping over an extended growing season. Therefore, early spring access for fertilization and initial harvest and late fall access for a final clipping are important for achieving maximum yields.

Table 6 compares yields on the drained and undrained treatments, number of clippings and clipping dates. Due to excess wetness, the undrained plot could not be fertilized in the spring and early growth was suppressed. Total yield was 12.4 $t.ha^{-1}$ on the drained compared to 9.5 $t.ha^{-1}$ on the undrained area.

Table 6: Effect of drainage and subirrigation on dry matter yield ($t.ha^{-1}$) of forage grass, initial clipping date and number of clippings.

	FORAGE GRASS ($t.ha^{-1}$)		
	DRY MATTER YIELD	FIRST CLIPPING	NUMBER OF CLIPPINGS
Undrained	9.5a	June 20, 1984	3
Drained	12.4b	May 17, 1984	4
Drained/Medium Subirrigation	12.5b	May 17, 1984	4
Drained/High Subirrigation	11.9b	May 17, 1984	4

The project has not been conducted for a long enough period of time to measure the effect of drainage on stand longevity. However, weedy broadleaf and grass species have already begun to invade the undrained site and it is expected that stand decline will be rapid.

Table 6 also compares yields of grass on the drained plot to yields on the two subirrigated areas. Although not significant, there appears to be a decline in yield due to subirrigation. Reasons for this are not evident at this time, although it is felt that it may be related to some internal soil structure degradation. There was a substantial climatic moisture deficit in 1984 and, therefore, it was expected that supplement irrigation would increase yields.

3.2.4 CORN

Silage corn is a common crop grown for dairy and beef animals and sweet corn is produced by many vegetable farmers. Since corn is a warm season crop, a long growing season is required to achieve high yields and adequate maturity. Late planting will generally result in low yields and poor grain production.

The objective of using corn as a test crop was to measure the affect of drainage on field access and seeding date and hence yield and maturity. Table 7 compares seeding date, yield, and % dry matter of corn grown on drained and undrained sites in 1984.

Table 7: Effect of drainage and subirrigation on dry matter yield ($t.ha^{-1}$) of silage corn, date of seeding, and dry matter at harvest Time in 1984.

	YIELD ($t.ha^{-1}$)	PLANTING DATE	% DRY MATTER
Undrained	8.3a	July 3	15.9
Drained	14.9b	June 5	23.4
Drained/Medium Subirrigation	15.3b	June 5	23.1
Drained/High Subirrigation	14.3b	June 5	22.5

Subirrigation was introduced in 1983 and 1984. Table 8 compares the various subirrigation treatments to the drained plot.

Although precipitation was quite different between the two years, subirrigation had no effect. Reasons for this are not apparent. Further investigations of the effect of subirrigation on internal soil structure are ongoing.

Table 8: Effect of subirrigation on yield of silage corn ($t.ha^{-1}$) in 1983 and 1984.

	YIELD ($t.ha^{-1}$) 1983	1984
Drained	21.2	14.9
Drained/Medium Subirrigation	23.6	15.3
Drained/High Subirrigation	20.8	14.3

4.0 CONCLUSIONS

This project has not been conducted for a sufficient period to draw definitive conclusions. However, some tentative conclusions are apparent from the data collected to date:

1. The period of time that soils are trafficable and workable is lengthened by drainage. This has a profound affect on yield of many crops because of early planting and the ability to carry out spring field operations such as fertilization, weed control, grass clipping, and tillage.
2. A drainage and pumping system provides sufficient water control to produce some water sensitive perennial crops.
3. Subirrigation has had little effect on crop yield to date. Yields of strawberries, forage grass, and silage corn have not been increased by the subsurface introduction of supplemental irrigation water.

However, in 1984 yield of marketable potatoes was significantly increased by subirrigation.

4. There is some evidence that subirrigation may be having a detrimental effect on internal soil structure.

REFERENCES

1. Coligado, M.C. 1983. The Climate of the Lower Fraser Valley. p. 86-91. In Soil Management Handbook for the Fraser Valley

2. de Vries, Jan. 1983. Entropment in the vicious circle of inadequate drainage, wet soils, compaction and ways of escape. p. 1-25. In Proceedings of British Columbia Drainage Workshop, 1983.

3. Luttmerding, H.A. 1980. Soils of the Langley-Vancouver Map Area. B.C. Ministry of Environment.

4. Timmenga, H.J., and D. Pedersen. 1984. Earthworm population densities in a drained and an undrained field of the Boundary Bay Water Research Project Unpublished.

5. Sondheim, M., and H.A. Luttmerding. 1984. Soil Drainage Maps of the Lower Fraser Valley.

6. Vold, T., N. Nagpal, M. Sondheim, and H.A. Luttmerding. 1984. Surface Soil Erosion Potential Maps of the Lower Fraser Valley.

7. ____________________. 1978. British Columbia Agricultural Statistics Yearbook.

Agronomic Aspects of Peatland Drainage

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ABSTRACT

Drainage system designs for peatlands vary according to the peat type, hydrology, topography and type of crop grown. Ditch or tile spacings are determined by the bulk density of the peat, depth and type of underlying soil and the gradient of the peatland surface. The location and design of drainage system outfalls in peatlands are important in order to minimize water quality effects on receiving streams.

Data are presented giving the results of peatland drainage studies on both a typical sloping fen and a raised bog in northern Minnesota. Water level control is recommended for most peatland drainage systems to reduce subsidence of the land and optimize available water to crop plants and prevent flooding.

Wilitng points for common agronomic crops were determined for several peat types, as were the available water contents. Techniques given in the literature for available water contents of mineral soils does not apply to peat soils.

INTRODUCTION

Minnesota has an estimated three million hectares of peatlands but only a small fraction of these lands are presently being used for crop production. Recent inventories show that less than 10% of the state's peatlands are presently cropped. Some of the most suitable peatland areas for crop production are located in the Glacial Lake Agassiz plain of S. Manitoba and N.W. Minnesota where development has dramatically increased in recent years.

Minnesota peatlands, which are most extensive in the northern area of the state, are presently being inventoried and evaluated for both consumptive and non-consumptive uses. Consumptive uses include the mining of peat for energy products, commercial horticulture products and industrial chemicals. Non-consumptive uses include agriculture, commercial forestry, wildlife management and preservation of natural areas.

Agricultural reclamation of peatlands has primarily been practiced in Europe and Asia. Russia, Finland, Ireland, Sweden and Germany have for many years utilized mined peatlands for both agricultural crop production and forestry. In the U.S. crop production on developed peatlands has mostly included vegetable crops, grain crops, forages and certain special crops. More recently, increasing energy prices have stimulated research on bioenergy crop production on peatlands as an alternate energy source. Commercialization of energy crop production in Finland, Sweden, United Kingdom and Ireland is presently underway. The principle energy crops grown on peatlands are hybrid poplars and willows and very high yields are reported.

This paper discusses the classification and properties of peat soils important for crop production, reviews the factors relating to drainage of peatlands, and gives data on available water contents for crops as well as wilting points for the three organic soil types. Problems related to soil and water management of cropped peatlands and selection of potentially suitable crops for these lands are also discussed.

SITE SELECTION AND EVALUATION

The primary considerations in selecting a suitable peatland area for agricultural development are road accessibility, proximity to market, demand for a specific crop, characteristics of the native vegetation cover, hydrology and topography and climate. Once an area is located and the crop selected, a more detailed evaluation is required. This detailed evaluation is accomplished by a comprehensive survey describing the physical and chemical properties of the peat on a specific site. The information from this survey will aid in determining the practices required to develop the site.

The comprehensive survey of the peatland site prior to cropping is designed to answer questions pertaining to drainability and fertility.

Factors influencing drainability include the topography of the peatland surface, the hydrology of the surrounding watershed, the degree of decomposition of the peat and the texture of the underlying mineral substrate. Potential reclamation areas are restricted to sloping peatlands, as suitable drainage is not economically feasible in other cases. Typically, the most suitable areas in Minnesota have a 1 to 2 m/km slope. Sites located in the upper part of the watershed are preferred due to runoff from uplands. Fertility is affected by pH, botanical origin and the inorganic fraction (ash) of the peat. When analyzing this fraction, both the amount and chemical compositon of the ash are considered. Reclaimed sites with 5.5 pH or greater are not limed. The liming of extremely acid sites such as Sphagnum bogs is cost prohibitive and often ineffective.

The slope and contour of the peatland surface (topography) can be determined by the use of topographic maps, aerial photos and on-site surveys. The topographic maps will show the general slope of the land, while on-site surveys will give greater detail when needed. Aerial photos will aid in evaluating the natural drainage of the area including the receiving stream and give an indication of the variability of the peat and vegetation cover of a peatland site.

Once the topography is evaluated, a detailed analysis of the hydrology of the peatland is initiated. The surface area of the surrounding watershed must be known in order to determine the amount of water to be diverted from the developed site. This amount of water is directly affected by precipitation, evaporation, run-off, ground water flow, and artesian water. The distance to the receiving waterway will also affect the drainage suitability of a site.

A systematic grid sampling method is implemented to obtain an overall representation of the site. Depth, uniformity, degree of decomposition, bulk density and botanical origin of the peat as well as properties of the mineral substrate are determined from these samples. If the peat is found to be less than three feet deep, the influence of the mineral substrate must be considered. A clayey substrate may impede drainage in some areas while a sandy substrate may cause ditches to be unstable. The degree of decomposition of the peat will affect its hydraulic conductivity and thereby the drainage system design.

Site Preparation

The fist step in the reclamation of a virgin peatland is the clearing of existing vegetation. The type of existing vegetation dictates when and how the clearing will take place. In the case of standing trees and shrubs, heavy machinery is required. In order to support this equipment, clearing is performed during the winter months when the peatland surface is frozen. The resulting debris is windrowed and burned at this time as a precaution against peat fires which are possible during drier seasons. Virgin peatlands with herbaceous cover only require deep milling for clearing. This is done following ditch installation.

In cases where woody plant remains impede the operation of machinery, deep milling is recommended. Ireland and Germany have experimented with the mixing of the mineral substrate with shallow peat with promising results. This deep plowing method results in a soil mix which has a higher pH than the peat itself, increased root aeration and a higher bearing strength. This method is recommended if the land is to be used as livestock pasture. Deep plowing or substrate incorporation requires reestablishment of the drainage system.

CHARACTERISTICS OF PEAT AND PEATLANDS

Peat may be considered a natural deposit occuring in a wetland environment. It is composed of plant remains that have grown, accumulated and subsequently preserved in a water-saturated site devoid of most oxygen.

The classification of peats or organic soils in the U.S. Department of Agriculture system (1975) consider three principal criteria in stage of decomposition (fibric, humic, sapric), botanical origin, and base status (low and high). The Canadian system proposed by Day (1968) is essentially similar to the U.S. system in stage of decomposition -- low (fibric), medium (mesic) and high (humic) organic material. Fibric peats in the U.S. organic soil classification system as shown in Table 1 are the least decomposed, have low ash content and bulk density and highest available water content. The hemic peat types have intermediate physical properties and medium acidity. The sapric peats are the most decomposed, with high bulk densities and mineral content.

These classification criteria or properties of the three major peat types affect the drainability, potential productivity and selection of crops for a given peatland. The properties of peat soils important for crop production are shown in Table 1. The bulk density of peat is one of the most important properties relating to drainage feasibility and successful crop production. It is negatively correlated with water content and positively correlated with decomposition -- i.e. low bulk densities have high total and available water content and high bulk densities have a low water content and a high degree of decomposition. The pH of peats, to some extent, affect the type of crop grown with the very acid Sphagnum moss subtypes of the fibric type being not very suitable for crops other than acid tolerant plants such as cranberries and blueberries.

The available water content of all peats, which essentially represents the difference between the upper limit of water (saturation content minus 25% air void spaces) and the lower limit of water (wilting point for most crops), is much higher than for high bulk density mineral soils.

High mineral content peats usually contain more plant nutrients and

Table 1. Properties of peat soils important for crop production.

Property	Peat Types		
	Fibric*	Hemic	Sapric
Fiber Content	> 66-2/3%	33-1/3 - 66-2/3%	< 33-1/3%
pH (H_2O)	3.0 - 4.5	4.5 - 6.5	5.5 - 7.5
Bulk Density	.04 - 0.1 g/cc	0.1 - 0.2 g/cc	0.2 - 0.3 g/cc
Available Water	55 - 70%	45 - 55%	30 - 45%
Mineral Content	Very Low	Medium	High
Suitable Thickness	Thick (> 90 cm)	Variable	< 90 cm
Preferred Slope	> 2 m/km	1 - 2 m/km	1 - 2 m/km
Nitrogen Content	Very Low (< 1.0%)	Medium (1 - 2%)	High (> 2%)

* Fibric soils of Sphagnum type are usually too acid unless limed.

Table 2. Laboratory data of a highly productive peat soil in NW Minnesota*.

Depth (cm)	pH (H_2O)	Ash Content (%)	Organic Content (%)	Bulk Density g/cc	Total Nitrogen Content (%)
0 - 30	6.3	9.0	91.0	0.15	3.1
30 - 60	6.2	6.0	94.0	0.13	3.0
60 - 90	6.2	5.3	94.7	0.11	2.8
90 - 120	6.8	5.7	94.3	0.12	2.8
120 - 150	7.0	6.1	93.9	0.14	3.0
150 +	calcareous, silty clay loam lake sediment				

* Roseau County, Minnesota.

peats with medium to high nitrogen content are preferred to those with low nitrogen as nitrogen is one of the most important plant nutrients.

The laboratory data given in Table 2 shows properties optimal for most crops grown on a productive peat soil. The pH or acidity is in the desirable range -- pH 6.2 - 7.0. The organic content and nitrogen content is very high and the bulk density or weight per unit volume is in the medium range.

Since nitrogen is one of the most important and expensive plant nutrients for crop growth, the following calculations are instructive: assume from Table 1 a bulk density of 0.15 g/cc or about 450,000 kg/ha of oven dry peat in the 30 cm surface layer. Then, 450,000 kg x 3.0% average N content = 13,500 kg N/ha. This represents a tremendous nitrogen reserve in the plants' rooting zone of this peat soil.

The release or mineralization of the native organic nitrogen forms in this soil making the nitrogen available for plant uptake is dependent upon the temperature of the soil in the rooting zone as influenced by the water table depth and summer season air temperatures. High temperatures and less acid soil conditions favor the release of nitrogen in an available form to the plants.

Peatlands are organic wetlands that vary according to hydrology, vegetation, topography and local geochemical influences. Examples of peatland vegetation types are open fens, forested fens, moss bogs and conifer swamps. Examples of topographic types are raised bogs, sloping fens, depressional bogs and blanket bogs.

There are now classification systems for wetlands including several peatlands types in both Canada and the U.S. developed by geologists.

DRAINAGE AND WATER MANAGEMENT IN PEATLANDS

One of the most important considerations in developing peatlands for crop production is the drainage system. The removal of surface water and some subsurface water will affect many soil properties and in turn influence plant growth. Adequate aeration of the soil's rooting zone is important to all crops except some aquatic species. A good drainage system includes large perimeter or intercept ditches which isolate the area to be cropped from the adjacent undrained peatland within the watershed and to divert runoff water from the nearby uplands.

A properly designed drainage and water control system in peatlands should prevent flooding of crops, reduce subsidence, minimize the possibility of frosts and fires, optimize nutrient availability and stimulate microbial activity because of increased temperatures in these normally cold and wet organic soils.

The amount of water available to crops grown on peatlands is affected by the stage of decomposition of peat, the level of the water table as it influences the aeration of soil and the variation in rainfall and evapotranspiration during the growing season.

Values for plant available water in the three major peat soil types has been reported by Brown and Farnham (1984). Table 3 gives data on the available water content of fibric, hemic and sapric organic materials. These data show that the upper limit of available water equals the saturated water content minus 25% air void volume to provide proper aeration for normal crop plant respiration. The lower limit of soil water available for plants is the amount in the soil when plants wilt irreversibly -- the wilting point of a particular soil.

The least decomposed peat type (fibric) has the highest available water content and the sapric the least. Large amounts of water available to plants are held at low tensions above an ever-present free water table in these organic soils. The range of available water content for hemic (partly decomposed) peat is from 12% (lower limit) to 63% (upper limit). Table 4 gives data on water content of a hemic organic soil during an above normal rainfall period as related to water table level. High water table levels at 30 to 60 cm below the peat surface result in conditions too wet for optimal plant growth while water levels 75 cm or greater are satisfactory since the normal plant rooting zones contain adequate air voids.

By contrast, the data in Table 5 collected during a dry period with a

Table 3. Plant available water in peat soils for crop production*.

	Peat Type % Water - Volume Basis		
	Fibric	Hemic	Sapric
Saturated	95	88	83
Upper Limit	70	63	58
Lower Limit	6	12	15
Available Water	64	51	43

* Upper limit equals saturation minus 25% air void volume. Lower limit equals wilting point of dwarf sunflowers.

Table 4. Water content of a peat soil with varying water table levels*.

Sample Depth (cm)	Water Table Level (cm)				
	30 cm	45 cm	60 cm	75 cm	90 cm
	- - - - - - % Water (Volume Basis) - - - - - -				
15	79	75	69	63	56
30	88	79	73	68	63
45	89**	88	76	74	71
60	-	89**	88	83	74
75	-	-	89**	88	82
90	-	-	-	89**	89**
105	-	-	-	-	89**

* Bulk density 0.15 g/cc — Hemic peat.
** Saturated with water.

water table at 70 cm shows from 32 to 50% available water in the upper 30 cm surface soil layers. This represents an ample supply of water for plants despite the dry season. Also during an extended early summer drought in a N.W. Minnesota bluegrass field (Table 6) the water content in the surface 5 cm of the soil was below the wilting point for this crop but contained sufficient available water below this depth so that the plants did not exhibit any wilting symptoms.

These data, shown in Tables 4, 5 and 6, illustrate the fact that in the case of peat soils where water table levels in drained peatlands are maintained at optimal level crop plants are not affected by either too much or too little rainfall.

Vegetation, through the process of transpiration, can have a great effect in reducing the water content in surface layers of peat soils. Table 7 compares water losses from a grass crop with that from bare peat. From a saturated condition on July 16, 1979 to August 13, 1979 the water content in the upper 7.5 cm layer of the grass field dropped from 85% to 3% in four weeks. In the second layer (15 cm depth) under grass cover the reduction was from 85% to 4.0%. On the other hand, the bare peat plot did not lose as much water due to evaporation probably because of a mulch effect on the surface reducing the temperature of the soil and blocking the capillary rise of water from below.

In a similar situation during an extended dry season in the summer of

Table 5. Water content in a bluegrass sod field during a dry period -- decomposed (Sapric) peat*.

Depth (cm)	Water Content % (Volume Basis)	Water Content of Soil Layers (cm)
0 - 10	32.0	3.20
10 - 20	50.0	10.00
30 - 45	80.0	12.00
45 - 60	83.0	12.45
60 - 75	85.0**	8.50
		46.15 Total H_2O in 70 cm

* July 1974, Anoka County, Minnesota.
** Saturated water table at 70 cm.

Table 6. Water content of a peat soil following an extended dry period -- NW Minnesota, summer, 1980*.

Depth (cm)	Bulk Density (g/cc)	Water Content % (Volume Basis)
0 - 2.5	.13	6.0
2.5 - 5.0	.13	10.0
5.0 - 7.5	.13	11.0
7.5 - 15.0	.13	13.0
30	.13	18.0
60	.12	45.0

* Wilting point water content is 10% or less.

Table 7. Water loss from peat soils due to plant transpiration -- summer 1979.

Depth (cm)	Weekly Water Content (Volume Basis) 7/16	7/23	7/30	8/6	8/13
Quack Grass Vegetation Cover					
7.5	85.0	28.0	20.0	6.0	3.0
15.0	85.0	30.0	28.0	10.0	4.0
Bare Peat (No Vegetation)					
7.5	85.0	35.0	40.0	14.0	6.0
15.0	85.0	38.0	38.0	27.0	28.0

Table 8. Water use by an energy crop (transpiration) compared to evaporation from bare peat*.

Depth (cm)	- - - - % Water (Volume Basis) - - - 7/9	7/25	8/9	8/22	8/28
Bare Soil					
0 - 5	38.0	32.1	40.0	37.6	33.5
5 - 10	39.4	37.8	39.9	41.1	38.1
10 - 20	39.2	56.4	62.7	47.4	47.2
20 - 40	60.6	69.0	70.6	69.3	55.6
Hybrid Willow (Energy Crop)					
0 - 5	37.5	26.6	26.1	19.0	18.2
5 - 10	36.6	28.5	18.4	17.1	19.8
10 - 20	38.2	40.9	28.9	18.3	22.5
20 - 40	55.3	46.2	30.0	28.1	33.6

* Extended very dry summer season -- 1984, St. Louis County, Minnesota.

1984 data were obtained comparing water losses with depth from bare soil and from a close-spaced field of hybrid willows (Table 8). The vegetation in these plots reduced the water content in all the soil layers by over 50% of that in the bare soil due to excessive transpiration by these vigorous willows.

Drainage System Design

The importance of the drainage system design on peatlands cannot be overemphasized. Drainage will affect many soil factors and in turn greatly influence plant growth. Adequate aeration of the soil is important to all crops. With increased aeration, microbial populations will increase and contribute to the release of nitrogen and other nutrients to the plants. Soil with a lower water content will also warm up more rapidly in the spring and permit the grower to utilize the full growing season. Proper drainage will also insure that the peat will bear the weight of farm machinery through the year.

The hydrological data from the comprehensive site evaluation in conjunction with the 100 year maximum storm event will dictate the needed discharge capacity of the drainage system. The degree of decomposition of the peat will affect the hydraulic conductivity and thereby the ditch spacing.

The drainage system is comprised of the following ditch types: interception, main, secondary, outflow and dispersion. The purpose of a drainage system on a peatland is to remove surface water and provide a zone of aerated soil for plant roots. Water level control structures may be used if precise regulations of the drainage norm is desired.

This system is oriented at a 45° angle to the slope (natural flow of water). The interception, main and outflow ditches should be dug during the winter months using large back-hoe or drag-line machinery.

The function of the interception ditch, which runs the entire perimeter of the development area, is to divert water flowing into the area from the surrounding watershed. Thus the width and depth of this ditch will be determined by the natural area draining into it. This ditch will connect to the out-flow ditch on the downslope side of the management area.

The main ditch is connected to the interception ditch and is moderately wide. As mentioned before, the 100 year maximum storm event is used in the contruction of this ditch. The depth of this ditch is usually to the bottom of the peat and the width is determined by the surface area of the reclaimed fields draining into it. This surface water is only considered in the construction of this ditch as the natural flow of surface and groundwater from the surrounding area has been diverted by the isolation ditch.

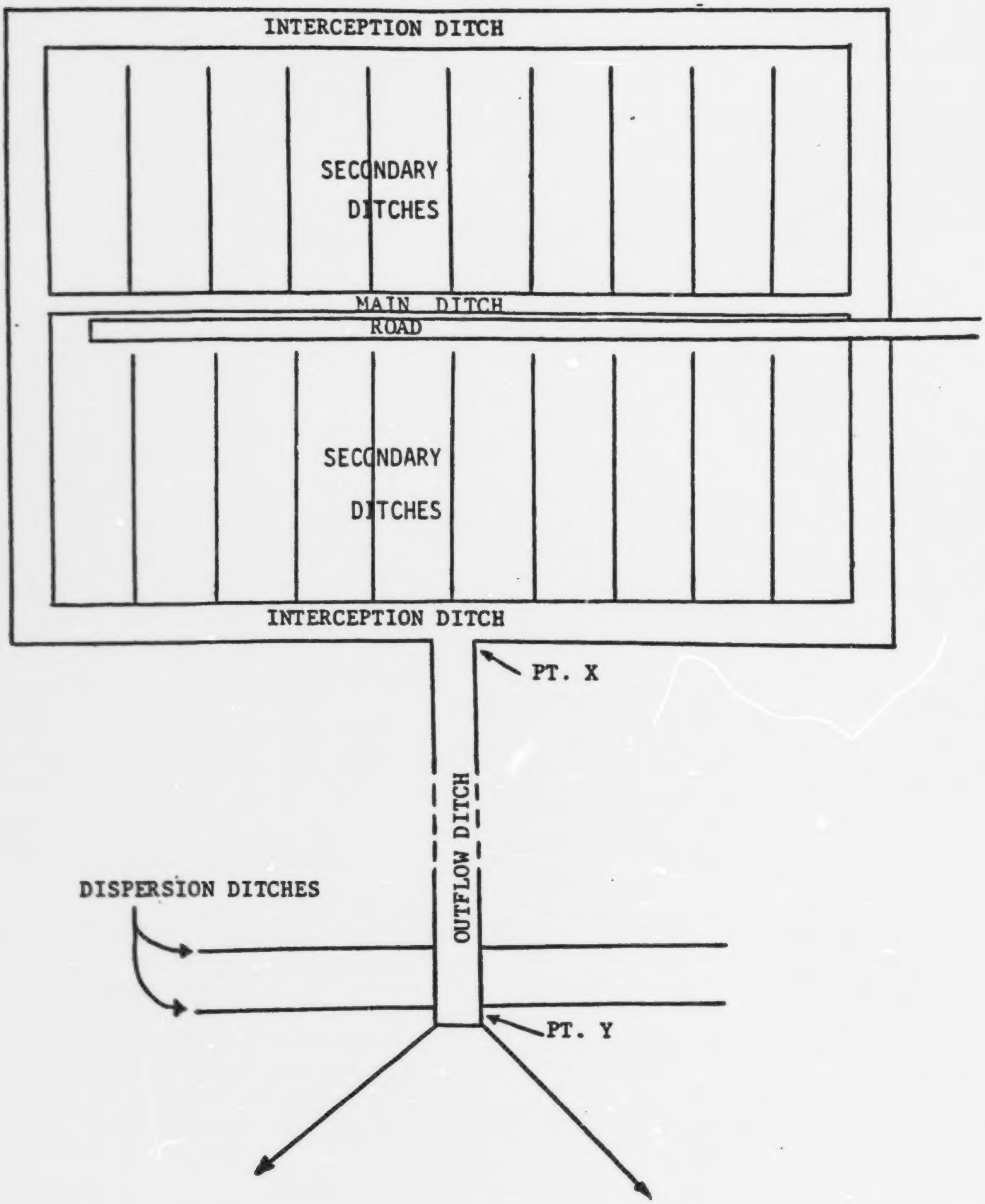
Secondary ditches are smallest and the most numerous ditches used in the drainage system. The spacing of these ditches will depend on the desired depth to the water table (drainage norm) and the degree of decomposition of the peat. The dimensions of the secondary ditches are determined by the machinery used and are not to exceed one meter in depth. These ditches are recommended not be dug to the mineral substrate. Water from the secondary ditches will flow directly into the main or interception ditch. Spacing of these ditches vary from 50 to 70 m for field crops and 20 to 50 m for vegetable crops. Wider spacings are possible in drier areas.

The outflow ditch drains all ditches in the management area and therefore is the largest in the drainage system. The width and depth are calculated by measuring the volume of water which is drained from the entire management area. It is very important to establish a sufficient hydrostatic gradient to achieve effective drainage. This gradient is a function of the slope of the peatland and the dimensions of the outflow ditch. To acheive this gradient, the difference in elevation between point X and point Y should be great enough to adequately remove water from this area in all instances. (Refer to Figure 1). This water is then distributed to the dispersion ditches.

The water from the outflow ditch may contain impurities such as organic colloids, particulates or plant nutrient. The dispersion ditches are a protective means whereby this water is filtered downslope through the surrounding peat before reaching the receiving cstream or lake. These purifying techniques are currently being used

Figure 1.

HYPOTHETICAL DITCH SYSTEM


INTERCEPTION DITCH
SECONDARY DITCHES
MAIN DITCH
ROAD
SECONDARY DITCHES
INTERCEPTION DITCH
PT. X
OUTFLOW DITCH
DISPERSION DITCHES
PT. Y

in sewage effluent treatment facilities on peatlands. The water quaility of surrounding lakes and streams is thereby not impaired. These ditches and are arranged in a fan shape configuration as shown in Figure 1.

Water Level Control Structures

There are various designs of water level control structures which can be used in drainage systems. These designs differ in the materials and methods of retaining the outflow water. Depending on the size of the ditch and its location in the system, wooden or concrete structures may be used. Inflatable rubber dams do not afford precise water level control, but have the advantages of mobility and less installment time over gates. These structures are used in various management situation. Water level control structures must be situated at regular intervals to achieve a uniform water table depth throughout the reclaimed site.

CROP SELECTION & SUITABILITY

Crop selection is dependent upon marketability, climate and suitable soil properties. The major limitation to agricultural development of peatland in northern Minnesota is the relatively short frost free period, normally June 1 to August 15. Agricultural crops potentially suitable for this cool climate are listed in Table 9. Some crops in this table may be more suitable than others due to special equipment

Table 5. Crops suitable on Northern Minnesota and Southern Canada peatlands.

Agronomic Crops	Horticulture Crops
Winter Wheat	Broccoli
Spring Wheat	Cauliflower
Barley	Cabbage
Oats	Celery
Wild Rice	Onion
Turf Grass (Sod & Seed)	Potatoes
Sunflowers	Spinach
Triticale	Beets
Lupine	Strawberries
Forage Crops	Raspberries
Pasture	Blueberries

of land requirements, as is the case in wild rice production. Susceptibility to viral and fungal diseases is another consideration when selecting a crop. Due to high humidity and dense plantings, conditions favorable for pathogen infestations are more prevalent on peatlands than upland soils. This is especially evident in the cases of bacterial and fungal diseases. Crop selection and associated management information can be obtained from a County Extension Agent or the University prior to field preparation and planting.

A recent bulletin published by Michigan State University (Lucas, 1982) discuss the formation, classification, physical and chemical properties of peat (organic soils) and their management for crop production. Estimates given for the extent of special crops (mostly vegetables) grown on peatlands in the United States were 280,000 hectares. These estimates, although incomplete, showed that Florida produces sugar cane on 130,000 ha of peatlands and other major crops grown on these soils included celery, radishes, sweet corn, carrots, lettuce and turf grasses. Elsewhere in the U.S. special crops produced on peatlands include mint, onions, cranberries, blueberries and asparagus.

Farnham (1983) estimated that in Minnesota over 276,000 hectares of peatlands are presently being used for crop production with the major crops being hay, forage and pasture. He also reported that vegetables, grain crops, corn, soybeans, wild rice, turf grass sod and grass seed are being produced on Minnesota peatlands. Development of peatlands for agriculture has increased dramaticaly in recent years particularly in N.W. Minnesota adjacent to Manitoba.

In Canada, Ontario produces over 12,000 ha of vegetables and special crops on organic soils. The Canada Department of Agriculture is the principle agency responsible for agricultural research on peatlands throughout Canada. In addition there are active agricultural research centers in most of the provinces. The Manitoba Peatland Farming Association, organized in 1982, presently has over 100 active farmer-members and they are conducting research on all aspects of peatland farming.

SUMMARY

The suitability of peatlands for the production of a variety of crops has been demonstrated by many research stations throughout the world. Successful development of these lands can be accomplished by careful site selection, construction of an adequate drainage and water control system, selection of suitable crops adapted to specific areas, and use of management practices designed to maximize both crop yields and quality of vegetable, agronomic and special crops.

REFERENCES

Brown, J. L. and R. S. Farnham, 1984. Water management in drained peatlands. Proc. 7th Int. Peat Congress, Dublin, Ireland. pp. 172-187.

Day, J. H., 1968. The classification of organic soils in Canada. Proc. 3rd Int. Peat Congress, Quebec.

Farnham, R. S., 1983. Use of peatlands for agriculture. Proc. Int. Symposium on Peat Utilization. Bemidji State Univ., Bemidji, MN. pp. 217-228.

Lucas, R. E., 1982. Organic soils (histosols): Formation, distribution, physical and chemical properties and management for crop production. Report 435 Farm Sci., Mich. State Univ. 77 pp.

Soil Survey Staff, 1975. Histosols. In: Soil Taxonomy. U.S. Dept. of Agriculture Handbook 436, pp. 211-226.

A Farmer's Viewpoint of Agricultural Land Drainage

Prepared by Allan Chambers for the
Agricultural Land Drainage Conference Nov. 20 1984

If given the opportunity to deal with the theme of soil, water and plant relationships most farmers on the prairies in 1984 would relate graphically how plants suffer from insufficient soil moisture and therefore how their incomes were also affected in dramatic fashion. My experience has more commonly been on the other end of the scale, excess water in the soil for optimum plant growth. We have also experienced drought ; occasionly we have both extremes in one year.

Managing a farm growing annual crops means ensuring a suitable seedbed, adequate fertility, suitable weed control and adequate machinery capacity to ensure timely operations are all in place. For Interlake farmers since first settlement it also means construction of adequate field drains to remove spring melt and heavy summer rainfall from our fields and adequate municipal or provincial drains to move water downstream at least 1/4 mile from our property. An important management skill we learn is how to effectively lobby municipal and provincial politicians about drainage and our major recreation is complaining about their incompetence in getting us our drains.

This evolution of management skills is natural given our experience. What are now the most fertile soils in our area were virtual floating bogs at the time of settlement. Reasonably stable agricultural was only possible after construction of major drainage works. Draining potholes in Western Manitoba is done to add a few productive acres to farms and to reduce the inconvenience of going around them. In our district by contrast good drainage systems are central to our economic survival.

During the last 10 years excessive rainfall in our corner during the growing season has been by far our biggest problem in growing and harvesting our crops. The area northwest of Riverton has been particularly hurt. About 200 farmers in that corner have lost all or part of their crop 7 out of the last 10 years in an area of fertile clay soils. Virtually everyone who was in a straight grain enterprise is now bankrupt and is out of business. That area has one political priority; more and bigger drains.

I've described an extreme example, but because quite heavy summer rains with resulting crop loss is an event we have all experienced it is an almost universal truism in our area that more drainage is 'good'. And frankly, not many of us are prepared to discuss drainage calmly and rationally. In our region you could add drainage to religion and politics as topics to avoid in polite company.

I have followed a similar pattern in learning how to manage our farm. In the late 60's and early 70's I had the municipal grader do several days work at a subsidized hourly rate cutting drains to take water off my farm land to the municipal ditches running along side.

Over the years since then I have noted that in years of heavy snowfall or after heavy summer rains these municipal ditches were overflowing into my fields with disasterous results to my crops. It seemed to be getting worse each year. It took awhile to sink in that the reason it was getting worse was because my neighbors upstream were doing exactly the same as I had done, dumping water into the ditch without regard for what happened next.

In early Aug. of 1975 we received 6 inches of rain during one night. We had over 300 acres of timothy and rye in the swath and a bumper crop maturing on the rest of the farm. The timothy stripped off in the heavy rain and 25% of the rye sprouted in the swath. There were areas of water ponding on the fields and extensive flooding from overflowing ditches. Eventually we got the crop off with rice tires and a straight cut attachment on the combine. Every bus. was dryed and harvesting costs were very high. I estimated that the value of my crop had declined by about $30,000 in that one night's rainfall.

In the spring of 1976 our fields were waterlogged and rutted. We mucked in part of a crop in June and watched it burn up in July. 1976 became the closest to a complete crop failure we had experienced until 1983 came along. There were strong similarities in 1983 to 1976. Excessive moisture in the spring, dry and hot later on. In 1983 we had good seeding conditions but received 7 inches of rain over a 10 day period in mid June. Cereals deteriorated badly even on the knolls as our clays were continuously waterlogged. Of course there was extensive ponding and our municipal drainage system again overflowed onto the fields. I did an item on the C.B.C. noon show describing how carp were spawning out in my wheat field. Needless to say the wheat yield was not too good. In fact it was one of three fields that we worked up in July when it was dry enough to get in with equipment.

The reason for this rather lengthy description of my trials and tribulations with excess moisture is to give you 'a farmer's viewpoint of agricultural land drainage' that is typical of every farmer's view in our area given our experience. We normally have too much water. The easiest way to improve each individual's situation is more and bigger drains particularilly if someone else pays the bill.

The fact that we often have excessive moisture on our relatively flat clay fields has dictated completly the cropping program that has evolved. I have noted that in periods of moderately excess moisture my forage crops produced well. Therefore we incorporate as much forage as we can manage and market into our rotation. We have had 100 to 200 acres of timothy for seed production in our rotation every year since 1970. Timothy thrives in relatively wet conditions and has made a major contribution to our economic survival over that time period.

There are negatives to having that much timothy in the rotation however. A few plants of perennial weeds like couch will lead to a solidly established infestation over the entire field after the 5 year rotation. I'm finding that couch seed in the soil is a major problem in trying to clean up these fields after breaking the timothy sod. Starting this past year we are going to try haying these fields for 2 or 3 years at the end of the timothy certification period partly to try growing out the couch and timothy seed in the soil. The result will be to stretch the rotation in grass from 5 to 8 years if we can market the hay.

The development by Monsanto of the chemical Roundup has the potential to help solve this major problem of couch control for us. I'll come back to the use of Roundup versus tillage because I believe it has very important ramifications for the amount of run-off that we will get from our agricultural areas in the future.

We have about 60 acres of very low, peaty areas in 3 parcels on our farm that I have come to realize cannot be protected from periodic flooding at a reasonable cost to the overall system. Therefore I have put them into a Reed Canary Timothy mixture and am harvesting relatively large tonnages of low value hay. One parcel has been in this mix since 1975 and is still producing reasonably well.

To insure a market for our forage byproducts we have moved into the beef business in two ways. We were partners in a feedlot until the pain became unbearable and we have developed a crossbred cowherd. We have sold 1000-1500 round bales per year to the feedlot since 1975.

In 1977 in order to have some better quality hay to feed with the straw I put a small 20 acre field into an alfalfa hay mixture. The organic matter in that field was very low and it was heavily infested with wild oats. If the hay is valued at $40 per ton that field has made a profit every year in the interim. Alfalfa hay is a viable cropping alternative for us. The only problem is in trying to break even marketing that hay though the cows.

I've noted one other thing about that field. There is virtually no run-off in spring or summer. We have also noted that when we break up alfalfa stands on other fields that the problem of ponding and run-off is much reducd in subsequent crops.

Thus we are looking for ways to increase the alfalfa we can grow. We recently leased 3/4 of a section for additional pasture so we will be increasing the size of our cow herd. More significantly in 1983 we judged the time right to buy some leaf cutter bees. We've been learning about that enterprise for the last two summers and will go to about 100 acres of alfalfa seed production. These two moves will allow us to switch a significant number of acres into alfalfa. I believe this can be profitable for us and also help use up other forage by-products. Equally important, it will reduce the runoff from our farm.

Finally we grow virtually no barley. Barley will simply not stand waterlogged soils in June which we seem to have one year in three.

So you can readily see that our farm has evolved in a particular direction with a rotation and an enterprise mix to deal with the soils and the climate with which we find ourselves working. More specifically the rotation is designed to minimize the disasterous effects of excess water on our fields, a condition I've come to expect with regularity. In 1984 we did not have ponding on our fields at all. I find myself somewhat dis-orierted; things are just not normal.

I should make the point that the main negative influence of excess moisture on crop yields in our area is the need for delayed seeding in the spring. I grew up in southwestern Manitoba on a farm with clay loam soils. One of the keys to my father's success was aggressive hard work in the spring when fields were worked twice prior to seeding. They were worked once, left for the wild oats to sprout and then worked again. When I began farming in the Interlake, in addition to unlearning much of what I had picked up at the University, I had to relearn spring work procedures. Firstly one does not drive on clay soils when they are wet unless you are working on a new process for making concrete. Secondly the season is usually too short to practise delayed seeding. In fact we often cannot get into the fields until long past optimum seeding dates. Potential yields decline rapidly if seeding most crops after May 21st. As a consequence there is very limited opportunity for spring cultural control of wild oats or perennials like couch.

Forages help us with spring seeding problems in two ways. In wet springs they are off and growing lushly and reduce the number of acres we have to handle. Secondly they are very beneficial in reducing wild oat populations. We find now after a couple of rounds of timothy in our rotation we have been able to grow certified oats. Incidently attempting to grow seed on fields that periodically have upstream water flowing in and out with a cargo of weed seeds can be a little frustrating.

The problems with spring seeding is one of the reasons we have been looking with great interest at winter wheat and the whole concept of zero-tillage. I believe that if we could develop systems of farming that would leave stubble standing undisturbed on a high % of the acres of Western Canada we could reduce downstream flooding more than by any other technique.

Our main hesitation in going to zero-tillage in a major way is that we are borderline in keeping our perennial couch under control on our farm with our present program. We seem to need a combination of Roundup and tillage to do a reasonable job. We were ready to try some winter wheat in 1983 and in 1984, but conditions were so dry we felt that the couch was too dormant for Roundup to work effectively. The cost of Roundup is too bloody high to gamble in that circumstance. The cost of Roundup is too bloody high period but I want to discuss that again later. I am concerned that the couch problem will get out of control if I go to zero tillage in a major way. If Roundup were more reasonably priced I would be able to move more significantly in this direction. We will pick our spots and try some winter wheat in the future.

I began this discussion by outlining how I learned to have a typical Interlake farmer's views about agricultural drainage. Then I described how our farm's rotation and enterprise mix has evolved almost completely in response to the fact that we often get flooding and waterlogged soils. My views on drainage have evolved considerably more recently however. If I'm on the right track we need to explore ways to convince other farmers and the general public.

My perspective began to change a little bit in 1976. That year we had a Danish exchange student with us who had spent the previous 6 months in central Australia on an irrigated farm. During the summer here he noted too much water sitting all over for three months and then three months of drought. He couldn't understand why we didn't install tile drainage to remove the excess and then in the dry period pump water upstream from the lake and use the tiles for irrigation. Having in effect just lost a crop and a half I had to admit that he had a point. It got me thinking, maybe we could manage this water resource rather than just try to get rid of it.

The real change in my viewpoint came between 1977 and 1980 during my term as a municipal councillor. After our disasters in 1975 and 76 my neighbors and I decided that our councillor of 27 years just wasn't good enough. We figured we needed a young hotshot who would solve all our drainage problems in short order.

Well I did manage to spend some taxpayer money that removed some bottlenecks near the bottom of our drainage system but did I ever get an education in the process.

I had one particular constituent who contributed to that education. His obnoxious behavior to me was probably similar to how I had reacted to the previous councillor. This individual had a very low peaty area of about 20 acres that flooded regularly each spring. The municipality had previously spent more money than the 20 acres would ever produce by making a deep cut as a roadside ditch though a very large ridge to the east of the field. The cut filled with snow each year. Because it was so deep and sharp the snow melted slowly and so acted as a dike. Solving the problem would have meant making the ditch wider. To do that we needed to buy a strip of his farm. At that point he decided that his ridge was worth $2000 per acre. Needless to say, negotiations were terminated.

It would have been far cheaper for the municipality to buy the 20 acres than to attempt to provide flood protection. The problem arose because the farmer is completely isolated from the overall economics of the system. From his standpoint if his 20 acres could be made more arable at no cost directly to him; why not? If the rules of the game were changed so that he carried directly even a small portion of the costs of providing the drain his perspective would change. Even better would be for him to receive some reward from society for turning that area into permanent wetlands. It would take a much lower expenditure of public funds to excavate 10 acres and put the soil up on the remaining area than provide drainage for it all. If any kind of overall economics had been applied, the original cut though the ridge should not have been made.

Going though the process of attempting to establish a Conservation District with our neighboring municipalities provided a similar education. The R.M. of Gimli is a relatively narrow strip running along Lake Winnipeg. We are the bottom end of a drainage system that reaches back 40 miles to the west. Most of the system is in the L.G.D. of Armstrong and is almost 100% made up of the Inwood-Meleb soil complex; a ridge and swail topography of classes 4 and 5 and lower. The ridges are stoney and have a thin high lime profile. The swails are subject to flooding. Under our existing system there is and will be no end of political pressure for additional drainage in that area. We have 4 provincial drains running through the R.M. of Gimli that originate in Armstrong. Over the years additional drainage in Armstrong was overloading these main drains and they were often creating major problems downstream. In an attempt to get a rational approach in place the province encouraged us to jointly form a Conservation District. Even though we could see Gimli taxpayers paying for drainage in Armstong forever our Council decided to support the idea. However the reaction by many farmers in Armstrong was appalling if not predictable. I recall sitting at the back of the hall at a public meeting while their Reeve and councillors endured unending verbal abuse. Each person wanted his drainage problem solved yesterday and what in blankety blank were their councillors doing proposing something that would see digging begin 30 miles away at the bottom end of the system. I suspect that most of you here today have attended many such meetings.

I drove home thinking "In a democracy this system cannot be made to operate in a rational manner." Since then I have come to realize that given the signals they receive these people were reacting in a completely rational way. We need to send different signals so that what is rational for the system becomes rational to them as individuals. That means direct costs to the individual for public drainage designed to benefit that individual. It also should mean providing a meaningful option for the individual to retain some of the water on his farm. This option could include direct help in construction costs and continuing rewards through property tax credits for maintaining wetlands. And in areas like Armstrong it might also mean on-farm demonstrations of practises like irrigating alfalfa.

There are areas in the Interlake with these types of soils where we have created a quite complete drainage system that removes all surplus water quickly in the spring and after heavy rains. Because of the high lime content these soils tend to restrict crop growth quite dramatically under dry conditions. I believe that we are expending large amounts of money to move water out of these areas that could be quite beneficial to crop growth at other times of the year. Could we not reduce downstream problems as well as help people upstream if some portion of this water was retained at its origin.

Another portion of my education as a councillor came from more careful observation of water movement in the spring. I farm land along one of the drains that flow out of Armstrong. The ice on Lake Winnipeg tends to create a cooler climate close to the lake in the spring. If temperatures rise to just above the freezing point snow melts back in Armstrong and water begins to run. Closer to the lake the ditches remain plugged with solid snow. We often have water moving downstream and spreading out over the fields repeatedly as it comes to snow dikes in the main drain. We love to gripe about Armstrong causing our problem.

My quarter had been in timothy and standing stubble each winter since 1972. In 1977 I broke the field and it was level and black in the spring of 78, just like a good farmer's field should be. That spring we had a very warm spell to begin spring breakup. The black soil warmed up quickly in the sun and the snow on that field turned to water in about one day. That blob of water moved downstream and in turn flooded 3 of my neighbors long before the Armstrong water arrived. I did not spread the word that the councillor was responsible for our flooding that spring. I don't suppose that this is news to most of you but it provided dramatic proof to me that bare black fields contribute more to agricultural land drainage problems than do stubble fields. It's interesting timing to be discusing this event. That quarter has just completed it's second round in forage this year. It has been worked 4 times since August and now stands ready to contribute to downstream problems again next spring.

Most of the complaints about our drainage system arise because water moves off agricultural lands into a municipal or provincial ditch or into a major waterway, accumulates in volume until the channel cannot contain it and then spills out and floods someone else's agricultural land or a village or a city. With the dry conditions in the fall of 83 and 84 field scrapers were hard at work in our area and all over the Red River Valley shaping fields to speed up the process. We have done our share on our farm also.

In the 1960's under the ARDA legislation the Icelandic River was cleaned out and deepened to provide improved drainage in that portion of the Interlake. We have now again reached or exceeded it's capacity and it is flooding in Arborg and Riverton in the spring. This fall many more field drains were being made at the head waters around Poplarfield. I'll bet the same was happening in the Rathwell district where the Boyne River rises despite all the publicity about how the Boyne is flooding Carman. Probably every creek and river in the agricultural area of Manitoba has an increased flood potential after all this work done by farmers during the last 2 years not IF but WHEN we return to wet conditions.

Our response has been to build bigger ditches, higher dikes, and more diversions around towns. We are spending millions and getting more and more flooding. Surely we are going at it all wrong. Shouldn't we be finding ways to keep a portion of that water upstream?

I want to come back to what is needed to make leaving stubble standing a more attractive option for farmers. At this stage I have to admit to summerfallowing 110 acres last year and we will have some again next year also. What's worse I even did some plowing this fall. We used a combination of tillage and Roundup on summerfallow because I just don't feel I have any viable options to clean up couch infestations. If Roundup were lower priced we would use heavier rates more often. We would be able to dispense with some or maybe all of the tillage.

Without a lower price on this chemical, the zero-till concept is just not viable to any significant degree in the northern prairies in my view. That would be a real shame. I am not one that advocates government interference at every turn but perhaps Mr. Wise and his provincial counterparts should sit down for lunch with the president of Monsanto.

Companies make legitimate pricing decisions all the time where they balance a margin per unit against projected number of units to be sold. In this case however society has a stake in making a particular desirable farming practise viable by influencing the direction of that decision by Monsanto. Perhaps the public could reimburse Monsanto for the research costs in developing Roundup. I am pleased to see how Hoerst has jumped on the conservation bandwagon promoting the use of their product to reduce soil erosion. Monsanto has not followed however as they also produce Avedex, the major soil incorporated wild oat herbicide.

The Zero Tillage Associations have the the potential to make a tremendous contribution to improved water management. They have been the major source of information for me in my attempts to reduce tillage. Use of the half rate of Roundup using ammonium sulphate and a surfactant; and the realization that Roundup can be very potent after a light frost were ideas first developed by farmers.

We have recently formed a Forage Producers Association that I hope can be equally useful in developing and trading information.

It's probably apparent by now that I have come to think in terms of water management rather than just drainage. On our farm we have begun installing outlet culverts on our field drains with gates on both sides; we are installing rock dams in the municipal ditches that run along side our low value grazing areas; and 70% of our cultivated acres do have standing stubble to catch snow and reduce runoff.

We are looking for ways to do more. In 1983 I noted the project in the Deloraine area to consolidate potholes and then to use the water for irrigation. It seemed to me that this might be the idea that would be the missing piece that would fit into our own operation. In the worst year for flooding, there was always a period during the summer when irrigation would have been beneficial. Although we have been improving our field drains leading off our farm we are also digging out for water storage an area that is most prone to flooding. If we can have a significant effect on water movement and if we can find a reasonable way to pump the water for irrigation we will expand the idea. My objective is to manage a 400 acre block so as to minimize or perhaps even eliminate run-off into the municipal ditch. The storage will be constructed to have shallow boundaries to provide optimum habitat for wildlife.

For this effort under existing rules in society; I will not notice any changes on my property tax notices; I will not be receiving any value from that portion of my taxes spent on drainage projects; I will have my quota base reduced for wheat board delivery opportunities; and I will receive reduced benefits under the Western Grain Transportation Act. I will try to fit into the PFRA grant system to make my idea a little more economic so we do have some policy which helps in the right direction.

The economics of water storage to me are not very good. However if we can develope a package that credits a farmer for reduced municipal costs and for increased wildlife production will we not give him an alternative to running to his municipal councillor for more drainage.

I feel very guilty admitting to this group that I am summerfallowing and plowing. I was amused at the similar trama of some of the zero-till farmers at having to burn on ocasion or how Jim McCutchion hated to lose his purity at going to a hoe drill. What fundamentally underlines many of the decisions that have been made on our farm is that I'm a conservationist. I think that the vast majority of farmers fall into the same category.

However the signals we receive from a vast array of programs provided by various levels of government are that society is not really interested in supporting us in our good intentions. If society is sincere in wanting us to farm in a way that will conserve soil and water it had better start giving us some genuine support. With all due respect to the many dedicated people in this room," we ain't been serious at all".

Let me finish up by listing some institutional changes that if implemented would send us positive signals;

- property tax credits for practises like storing water, maintaining wetlands, leaving stubble standing, planting and maintaining shelterbelts.
- full and prompt compensation for waterfowl damage
- a reduction in the price of Roundup or development of alternatives.
- support for research into and tax incentives to purchase equipment that will seed into stubble
- development of winter and perennial cereals.
- removal of the penalties against forage production in the Western Grain Transportation Act.
- introduction of direct charges to property owners for drainage works.
- a Wheat Board quota system that does not reward summerfallowing and breaking of marginal areas.

The list could go on but I hope you get the idea.

I am not proposing that we stop all drainage improvements or that we fill in existing drains. However I am convinced that farmers could do much to reduce the flow of surplus runoff in our drainage system in a manner that is economical for the whole system. My proposed list is not costly for governments. Most of it would not cause any political hassle. It would cost far less to implement than the potential savings in the budget of the Water Resources Branch if such a change in approach took place. Consider the reduction in stress on the administrators of our prairie drainage system IF every quarter section on the prairies had storage capacity for the first inch of runoff and IF there was enough stubble and surface organic matter to keep snow on fields and to increase the amount of moisture that would soak into the soil by one inch.

I probably am preaching to the converted this afternoon. I know that our chairman and the majority of staff in both agriculture and in water control believe in and work for water management. Every municipal official whom I've tried these ideas on agrees with the concept. However we all run into the fact that the political pressure from most farmers is for more blind drainage. In a democracy that pressure prevails. We must structure our institutions to change their minds. Only then can we hope to achieve real water management.

TRANSIENT GROUNDWATER FLOW SURROUNDING A RECHARGE SLOUGH IN A TILL PLAIN

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ABSTRACT

Knowledge of the groundwater flow system around a slough aids in the resolution of conflicting opinions on slough drainage. This study reports on the flow system around a typical temporary slough in a low relief till plain landscape. The site is located in a regional groundwater recharge area, with till of low hydraulic conductivity overlying a shale aquifer. The distribution of soil profile types in the landscape indicates a wide range of water regimes around the sloughs.

Instrumentation at the site revealed an annual cycle of water levels that was related to spring ponding of water in the slough. A band of saline soil in the cultivated field around the slough formed as a result of a local groundwater discharge. Numerical simulation of the flow system, under conditions of ponding, surface saturation, and evapotranspiration, helped to clarify and extend the field observations.

Each depression in the landscape has a local flow system that is superimposed on the regional system. The size of the local flow system is restricted by the low hydraulic conductivity of the till. The flow alternates seasonally between outward and inward flow, with little recharge of the shale aquifer. Hydraulic conductivity, water supply to the slough, and the amount and timing of infiltration and exfiltration all affect the local flow system. Temporary sloughs, such as the one studied, do not benefit agriculture, but drainage of these sloughs raises other concerns.

INTRODUCTION

Sloughs in agricultural areas have often been the subject of controversy. They have been variously viewed as: wetlands providing wildlife habitat, an obstacle to mechanized agriculture, part of the water resources of the region, or storage for rainfall and snowmelt that prevents stream flooding. The groundwater flow system around the slough has important implications in all of these aspects.

This study reports on the transient flow system associated with a slough in a particular hydrologic setting. An attempt was made to determine the factors influencing the groundwater flow so that the results could be generalized to other hydrologic settings.

SITE DESCRIPTION

The site, consisting of a group of sloughs, is located just east of the town of Hamiota, Manitoba, in the south west quarter of 11-14-23W1. This 64-ha field contains over thirty sloughs, and is usually cropped to cereals or annual oilseeds. Other fields in the vicinity have similar numbers of sloughs.

The landscape is a till plain containing numerous closed depressions and having a hummocky appearance, although the local relief is only about 2 m. Many of the depressions contain temporary sloughs, which fill with water in the spring, become dry in the summer, and develop a lush vegetation cover. The area has little or no integrated surface drainage. Glacial meltwater channels are prominent features, but they are not part of any present drainage system. Similar landforms cover wide areas of Manitoba, Saskatchewan, and the adjacent U. S. states.

The stratigraphy (Figure 1) was determined by Lissey (1968). The till deposit, about 21 m thick at this location, is of mixed origin, containing clasts of various sizes in a clay loam textured matrix. Because of its high clay content and compact form, the hydraulic conductivity of the till is very low. The upper metre of till that is subject to pedogenic disturbance would be expected to have a higher conductivity. Below the till is the hard, gray, highly-jointed Odanah shale. The hydraulic conductivity of the shale is approximately three orders of magnitude greater than that of the till.

The site is part of a regional recharge area in the Oak River basin mapped by Lissey (1968), containing fast and slow recharge sloughs, where water infiltrates to recharge the shale aquifer. The water table is in the upper part of the till deposit. The hydraulic head in the shale is much lower than the water table, indicating downward flow in the till. Groundwater in the shale aquifer flows southward and discharges south of the town of Hamiota. Lissey indicates that recharge areas such as this cover 70% of the Oak River basin.

Al-Taweel (1983) made a detailed study of the soils of the site. He found striking variations in the type of soil profile that had developed in different topographic positions, and related these to variations in the long-term water regime. He also described a band of saline soil that partially encircles the principal slough and investigated secondary salt and carbonate deposits in these soils.

FIELD RESEARCH

The instrumentation for groundwater measurement were installed on two transects extending radially outward from the center of the principal slough. Water table observation wells varied from two to six metres in depth, depending on topographic position. Shallow piezometers were arranged in nests of two or three piezometers per nest, with tips at 1.5 m to 6 m depth. In addition, a portable tensiometer was used to obtain the potential beside each piezometer nest in the unsaturated zone, at 45 cm depth. Readings were taken every three to five weeks, with additional ones taken in the spring and early summer when conditions were changing rapidly. Levels of water in the sloughs and time of drying were also noted. Soil temperature was monitored, as well, using arrays of thermocouples between 2.5 cm and 1.5 m depth.

Over the four year observation period, the water levels in all of the wells and shallow piezometers rose and fell in an annual cycle (Figure 2). This cycle was apparent along the whole transect from the knoll to the depression, although the amplitude increased considerably in and near the depression. The phase and shape of the cycles also varied along the transect. In the depression, there was an abrupt rise in April, and a rapid decline in July or August. The rise and decline were more gradual and occured somewhat later in the year, in the area between the knoll and depression. Under the knoll, there was a slow rise, beginning in June, to a maximum in October, and an equally slow decline until the following June.

Vertical gradients below the water table, as revealed by the shallow piezometers, were always rather small, and frequently non-existant. Gradients in the unsaturated zone generally corresponded in direction to those in the saturated zone, although the magnitude was often greater. Figure 3 is a typical equipotential diagram. In the area between the knoll and depression, upward gradients were associated with a falling water table, and downward gradients, with a rising water table, suggesting removal and addition of water at the surface. In the spring and early summer, when water was ponded in the depression, vertical gradients were insignificant. The decline of the water table in the depression, during July, August, and September, was accompanied by an upward gradient, presumably due to evapotranspiration. At the knoll position, the gradient was upward most of the time, regardless of the movement of the water table.

The annual cycle of the water table must be related with the rapid addition of water to the system that occurs in the spring, in particular, with the ponding of water in the depression (Figure 4). Field observations indicate that as soon as the frost thaws in the slough bottom to permit infiltration, the water table below the slough rises and coalesces with the ponded water. Some outward groundwater flow away from the slough is undoubtedly caused by this elevated water table. One explanation, later rejected, for the delay of the water table rise along the transect from the depression to the knoll involves a slow outward flow from the depression which reaches the location of the knoll after several months of travel.

The band of saline soil in the cultivated field around the slough indicates that there is a net upward flux of groundwater in this zone. Seasonal proximity of the water table to the surface could account for this. Well-developed and non-saline soils outside the saline ring indicate a net downward flux at these locations. Evidently, as the water table becomes deeper below the surface, exfiltration from the water table becomes insignificant in relation to infiltration from normal precipitation. There is also a band of poorly-developed but non-saline soil inside the saline ring. Here the seasonal water table is even higher, but the discharge is fresh water because of the very short flow path from the slough.

SIMULATION RESEARCH

Groundwater research in the field is restricted in its scope by the site conditions that prevail and, in particular, by the weather conditions that occur during the study period. Interpretation of the field data, according to the accumulated principles and theories of hydrogeology, is always required. Simulations complement field studies because they permit experimentation with a model of the field system where the various factors that affect groundwater flow can be varied independantly. Transient, saturated and unsaturated flow, as occurs at the Hamiota site, is described by a non-linear parabolic partial differential equation. A numeric simulation of this equation by the finite difference method over a two-dimensional cross-section requires the solution of a matrix of simultaneous non-linear equations at each time step. Brutsaert (1971) has developed an efficient computer method, using Newton linearization, to perform this simulation.

When given input consisting of the dimensions and physical properties of the system plus the initial groundwater conditions, the program displays the distribution of saturation and potential at various times during the simulation run. The flow system chosen for simulation at the site east of Hamiota was one half cycle of the topography along a cross-section from the knoll to the depression. A homogeneous isotropic medium with an impermeable lower boundary was specified, with a level water table about three metres below the bottom of the depression, and the soil above the water table in capillary equilibrium with the water table. These conditions approximate the system in the field just before the spring infiltration begins. The first runs were started with water ponded in the depression in order to observe the growth and dissipation of the groundwater mound. Later runs were started with the upper metre of soil along the whole transect at saturation in addition to the ponded water. This was an attempt to simulate the wet conditions that might occur in the spring due to thawing of frozen soil and infiltration of snowmelt. Finally, flux terms were introduced to simulate evapotranspiration at the soil surface along the transect.

A number of significant results were obtained from the simulation runs (Figure 5). Many of these are consequences of the very low hydraulic conductivity of the till, which severely restricts water movement. The growth of the groundwater mound by infiltration below the slough corresponded reasonably well with behavior observed in the field. The recession of the water level in the slough was mainly due to evaporation, rather than seepage. Similarly, once the slough had dried, the dissipation of the groundwater mound was primarily due to loss of water by evapotranspiration, although horizontal saturated flow was also a significant mechanism. Outward flow from the depression did cause a rise in the water table at the edge of the depression, but had no effect on the water table along the rest of the transect. It was only when initial surface saturation was introduced that a water table rise similar to that recorded in the field appeared in the simulation. A rise and fall was produced when both initial surface saturation and evapotranspiration were included in the model. Limitations in specifications of data precluded duplication of field observations in a quantitative manner but the results outlined here do help to identify factors that are important in the flow system.

DISCUSSION

The Groundwater Flow System

At the study site east of Hamiota, a local groundwater flow system is superimposed on the regional flow system. The driving force for the local system is seasonal ponding, saturation, or evapotranspiration at the surface. In general, the flow is nearly vertical in the unsaturated zone and nearly horizontal in the saturated zone. This is a consequence of the contrast in hydraulic conductivity between the unsaturated and saturated flow medium. Of course, there is not a sharp boundary between these two zones as there would be in the case of a stratigraphic change.

Much of the flow is focused on the depression. That position has the widest range of water table level: from ponded water in the spring to several metres below the surface in the fall and winter.

The area of influence of the slough is restricted by the low hydraulic conductivity of the till. While water is ponded in the slough, there is some outward saturated flow and part of this is diverted upward by evapotranspiration. Later in the summer, when a depression of the water table has formed below the slough, a reversal of flow occurs so that groundwater moves toward the slough. At certain times of the year, the water table in the cultivated field near the slough is within a metre or two of the surface. Calculations indicate that even at these times, capillary rise will not supply a significant amount of water to the crop. However, crops with roots that penetrate to these depths can certainly withdraw the water. Outside the area of influence of the slough, episodes of infiltration and exfiltration act to raise or lower the water table.

Meyboom (1966) studied the groundwater flow system around a similar slough in the Allan Hills of Saskatchewan. The till deposit there is much thicker and the relief and regional slope are greater than at the Hamiota site. The till also has a higher hydraulic conductivity so that the area of influence of the slough was correspondingly larger. Meyboom discovered the alternation between outflow from the slough in the spring and early summer and a late summer reversal of flow back toward the slough. He attributed the flow reversal to movement of groundwater toward the water table depression created by the willow ring and the vegetation filling the slough.

The groundwater in the till is not particularly useful as a source of water. Shallow wells in the till have a very low yield unless they happen to intersect a lens of stratified material within the till. Water from the till does recharge the shale aquifer, but the flow across the 17 m of till must be very slow because of the low hydraulic conductivity. The recession of the ponded water in the spring and summer cannot be directly related to recharge of the deep aquifer. Most of this water is lost by direct evaporation or enters the local flow system and is lost by evapotranspiration. Meyboom reported that the slough in the Allan Hills alternately recharges and discharges the regional groundwater. The net effect of this type of a local flow system may be small and certainly is difficult to determine.

Factors Affecting Shallow Groundwater Flow

The local groundwater flow system around a slough is determined by the regional hydrologic setting, as modified by local additions and removals of water. When the regional flow system is weakly expressed, it can be dominated or reversed by the local flow system. At the Hamiota site, a sequence of local seasonal recharge and discharge zones have developed within a regional recharge area, as a response to the hummocky topography. Soil properties, particularly hydraulic conductivity, also have a great influence. Low conductivity materials, such as the till at the Hamiota site, allow large hydraulic gradients to develop, but flow rates will be low, and flow distances, short. The converse is true for materials of high conductivity. Another factor is the water supply to the slough. The persistence of ponded water in the slough depends on the balance of the water supply with losses by evaporation from the surface and inflows or outflows by seepage. In a study of ten sloughs in central North Dakota over a five-year period, Shjeflo (1968) determined that 48% of the water supply was from direct rainfall on the water surface, but that 31% was from snowmelt and 21% was from rainfall runoff in the surrounding watershed. The latter two sources can be quite variable. Refering to the North Dakota study, Eisenlohr (1972) concluded that the conditions that favoured a large contribution from snowmelt were a snow cover that remained until spring and then melted rapidly while the ground was still frozen. Likewise, rainfall that occured after the soil surface had been saturated by a previous rain favoured runoff into the depression.

In the area surrounding the slough, water is added to the flow system by infiltration and removed by exfiltration. These exchanges, together with deeper flows, determine the transient position of the water table. Infiltration can result from snowmelt or thawing of frost in the spring, or from rainfall in the summer and fall. At the Hamiota site, infiltration in the spring appears to be responsible for the annual rise of the water table along the transect from the knoll to the depression. Similarly, Shjeflo (1968) reported that in May, the water table at the edge of a slough rose to 60-90 cm above the water level in the slough. He attributed this to thawing of frost in the soil. Exfiltration is primarily due to consumption of water by plants, and it becomes dominant in the summer when temperatures are highest and the plants are actively growing. In the winter, water can also move upward from the water table to accumulate as frost near the soil surface. The annual decline of the water table at the Hamiota site is likely a result of exfiltration by both of these mechanisms.

Application of Groundwater Data

A good deal of information about local and regional groundwater flow systems can be obtained without detailed hydrogeological study. Lissey (1968) mapped regional recharge and discharge areas by observing natural vegetation communities around undisturbed sloughs in the early fall. The rate of water level recession over the summer months and the salinity of the water can similarly be used to indicate slough hydrology. Soil profile types are also good indicators. A profile that has a well-developed "B" horizon and a deep solum that is free of carbonates suggests a long-term net downward flux of water. Conversely, a net upward flux is suggested by a poorly developed profile with an accumulation of carbonates and salts near the surface. Hydraulic conductivity of the materials is a critical factor, but this can often be estimated from descriptions of the surficial deposits or soil parent materials.

Sloughs are of little benefit to agriculture and do occupy land that could otherwise be used for crop production. At the Hamiota site, crop growth in a narrow band at the edge of the slough is sometimes enhanced by the shallow water table there, but growth is often depressed by the salinity that has developed around the slough. Sloughs that regularly go dry in the summer are not even useful as waterfowl habitat or as a source of water for agriculture. Knowledge of the groundwater flow system associated with a slough provides an insight into the changes that might occur when the slough is drained.

Consequences of slough drainage include a reduction in groundwater recharge, a loss of stored water, and an increase in water entering the surface drainage system. Recharge is not necessarily beneficial, particularly if it results in wet and saline conditions in an adjacent discharge area. Drainage of small and temporary sloughs into one larger slough is an alternative to complete removal of the water that offers some advantages. Guidelines for slough drainage should be formulated to weigh the benefits and consequences of slough drainage, but must also consider the hydrogeology of the slough and its environment.

REFERENCES

AL-TAWEEL, B. H. 1983. Soil genesis in relation to groundwater regimes in a hummocky ground ground moraine area near Hamiota, Manitoba. Ph. D. Thesis, Dept. of Soil Science, University of Manitoba, Winnipeg, Manitoba.

BRUTSAERT, W. F. 1971. A functional iteration technique for solving the Richards equation applied to two-dimensional infiltration problems. Water Resour. Res. 7: 1583-1596.

EISENLOHR, W. S., Jr., and others 1972. Hydrologic investigations of prairie potholes in North Dakota, 1959-68. U. S. Geol. Survey Prof. Paper 585-A.

LISSEY, A. 1968. Surficial mapping of groundwater flow systems with application to the Oak River basin, Manitoba. Ph. D. Thesis, University of Saskatchewan, Saskatoon, Sask.

MEYBOOM, P. 1966. Unsteady groundwater flow near a willow ring in hummocky moraine. Jour. Hydrology 4: 38-62.

SHJEFLO, J. B. 1968. Evapotranspiration and the water budget of prairie potholes in North Dakota. U. S. Geol. Survey Prof. Paper 585-B.

LIST OF FIGURES

Figure 1: Stratigraphy at the site east of Hamiota.

Figure 2: Hydrographs of shallow piezometers at four topographic positions: (a) Depression. (b) Lower slope. (c) Middle slope. (d) Crest.

Figure 3: Hydraulic head distribution at the site east of Hamiota.

Figure 4: Seasonal fluctuation of the water table.

Figure 5: Saturation and potential output from simulation runs: (a,b) Infiltration of water ponded in the depression. (c,d) Persistence of the groundwater mound below the depression. (e,f) Progressive water table rise due to initial surface saturation. (g,h) Falling water table due to evapotranspiration at the surface.

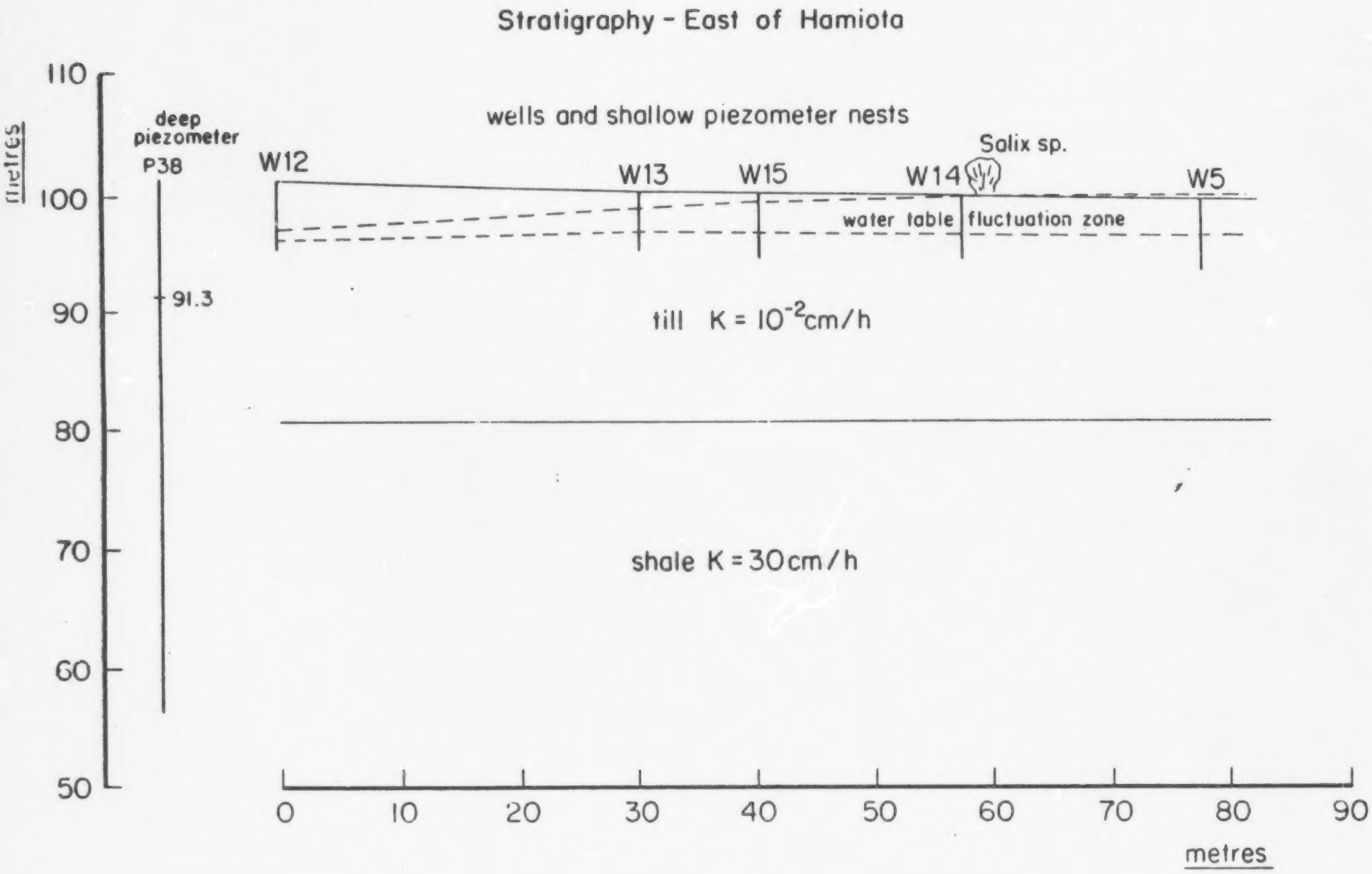
Stratigraphy - East of Hamiota
metres
110
100
90
80
70
60
50
deep piezometer
P38
91.3
wells and shallow piezometer nests
W12
W13
W15
W14
Salix sp.
W5
water table fluctuation zone
till K = 10^-2 cm/h
shale K = 30 cm/h
0
10
20
30
40
50
60
70
80
90
metres

FIGURE 1

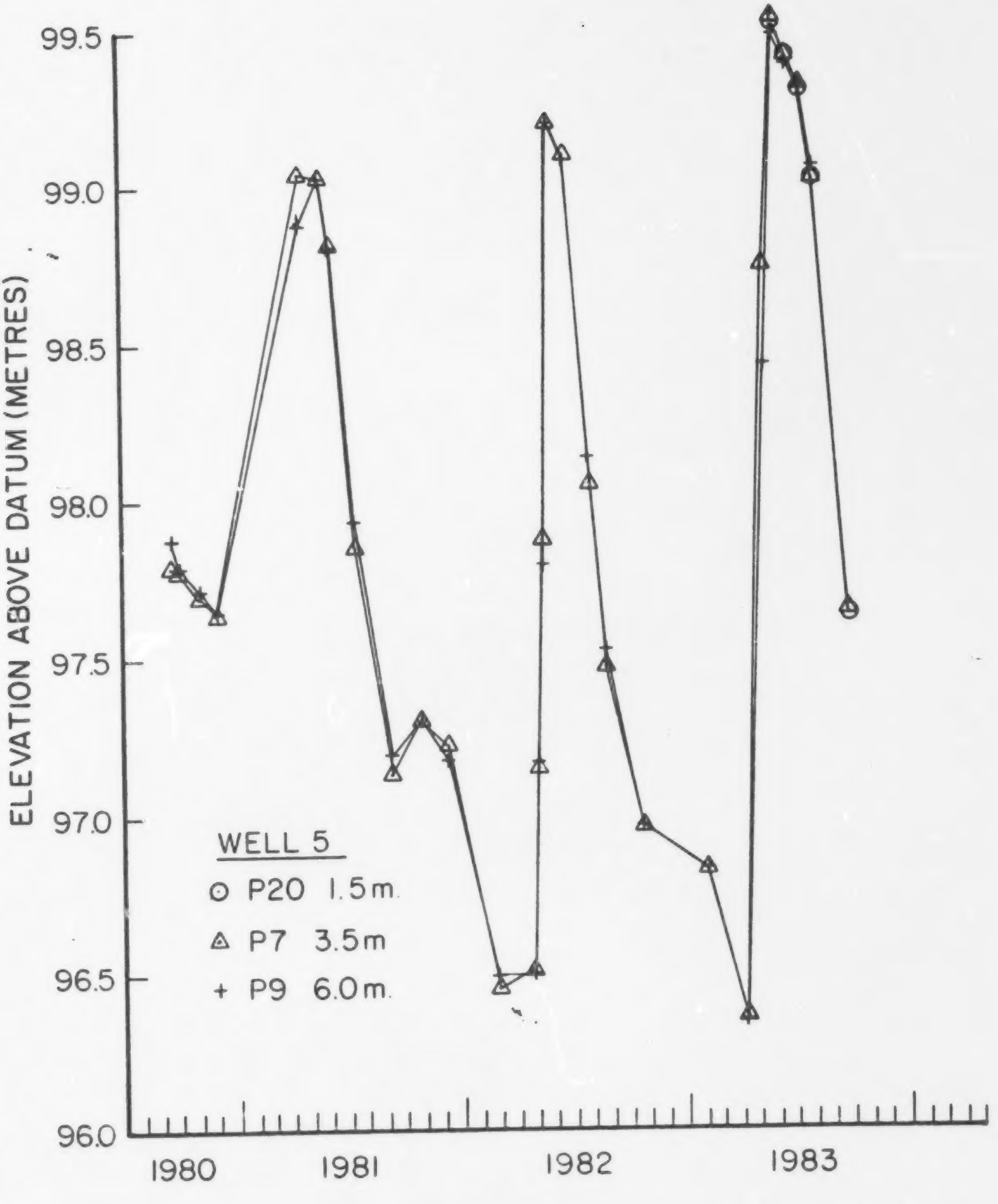
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
ELEVATION ABOVE DATUM (METRES)
1980
1981
1982
1983
WELL 5
⊙ P20 1.5m.
△ P7 3.5m
+ P9 6.0m.

FIGURE 2(a)

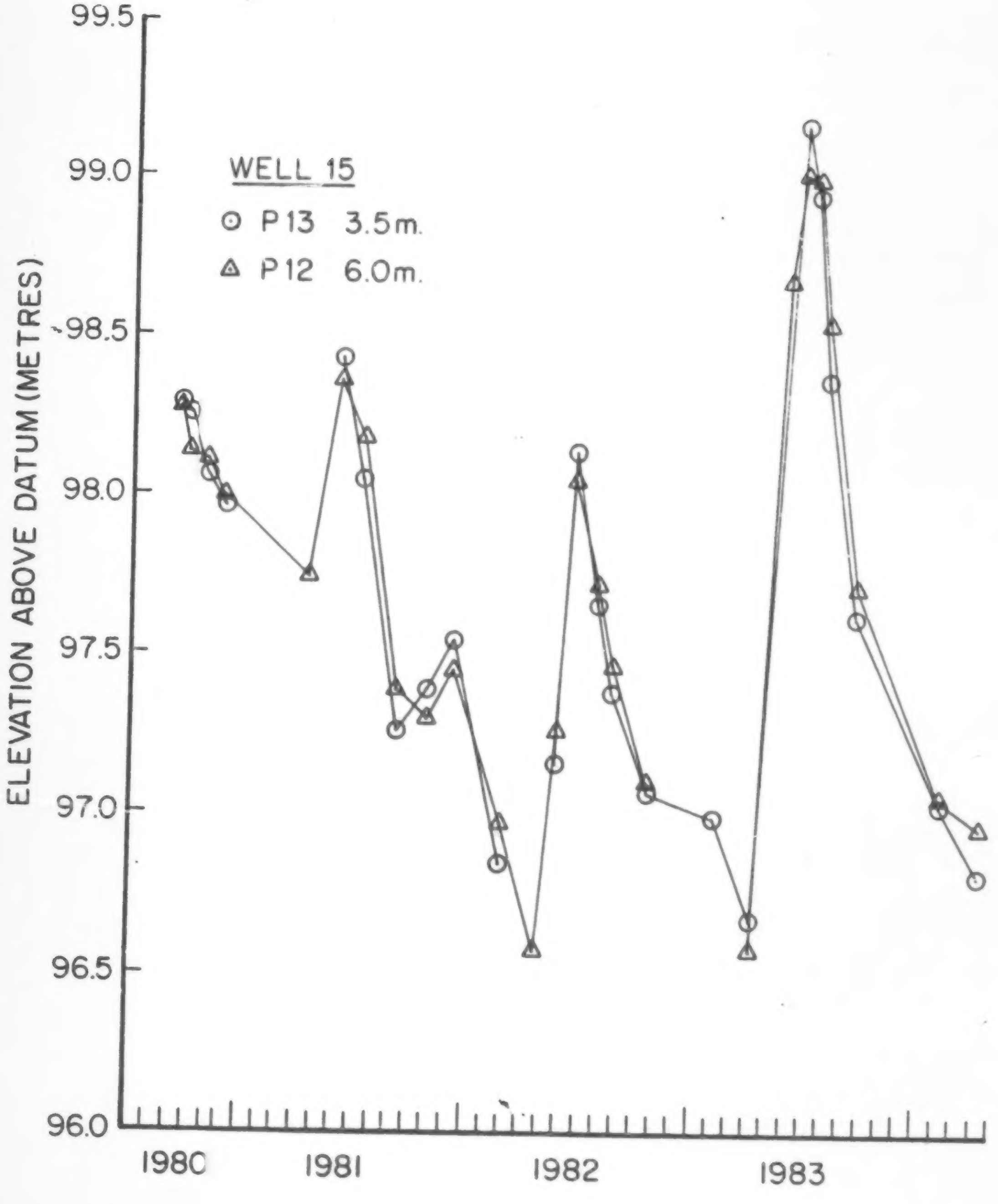
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
ELEVATION ABOVE DATUM (METRES)
WELL 15
○ P13 3.5m.
△ P12 6.0m.
1980
1981
1982
1983

FIGURE 2(b)

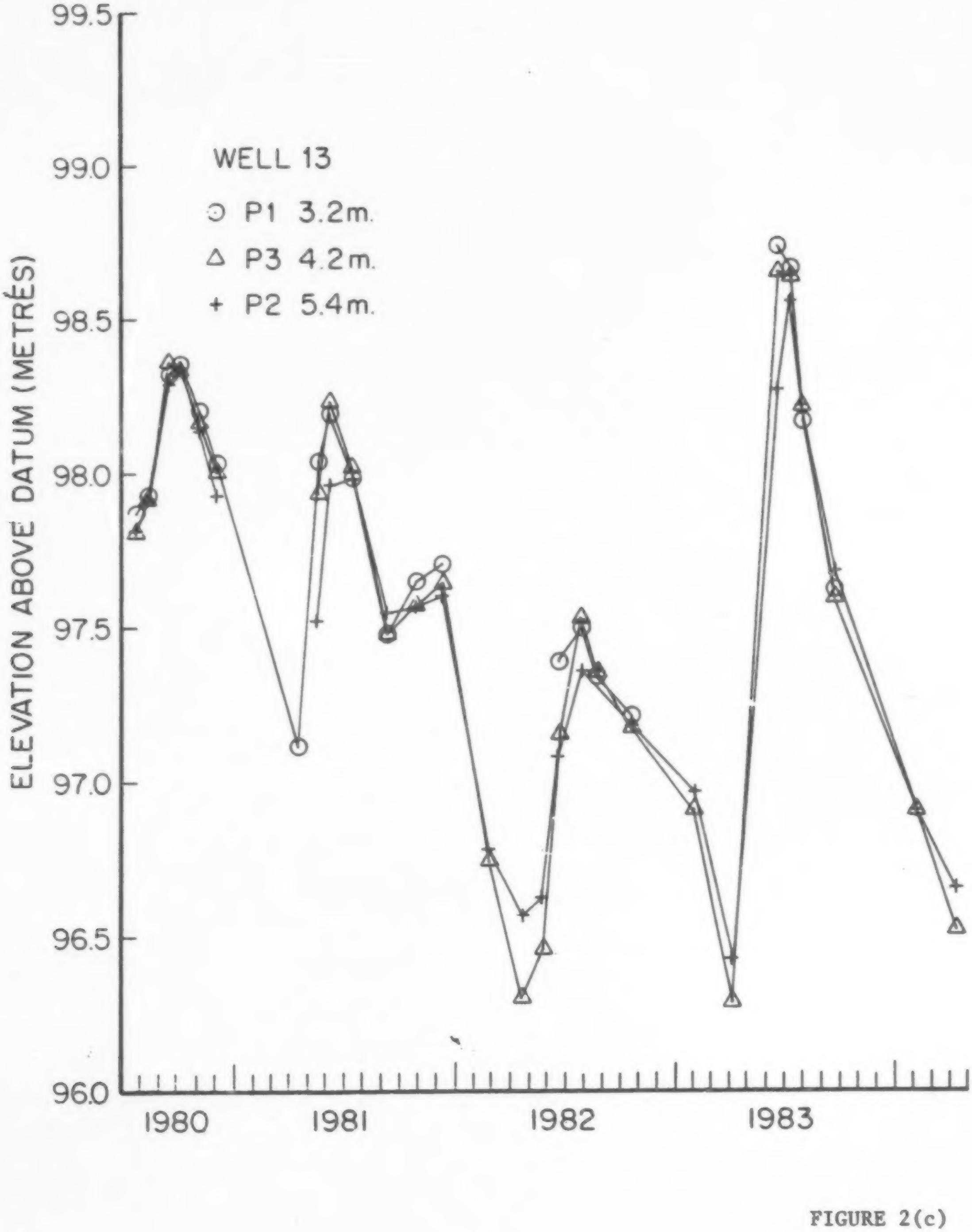
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
ELEVATION ABOVE DATUM (METRÉS)
WELL 13
○ P1 3.2m.
△ P3 4.2m.
+ P2 5.4m.
1980
1981
1982
1983

FIGURE 2(c)

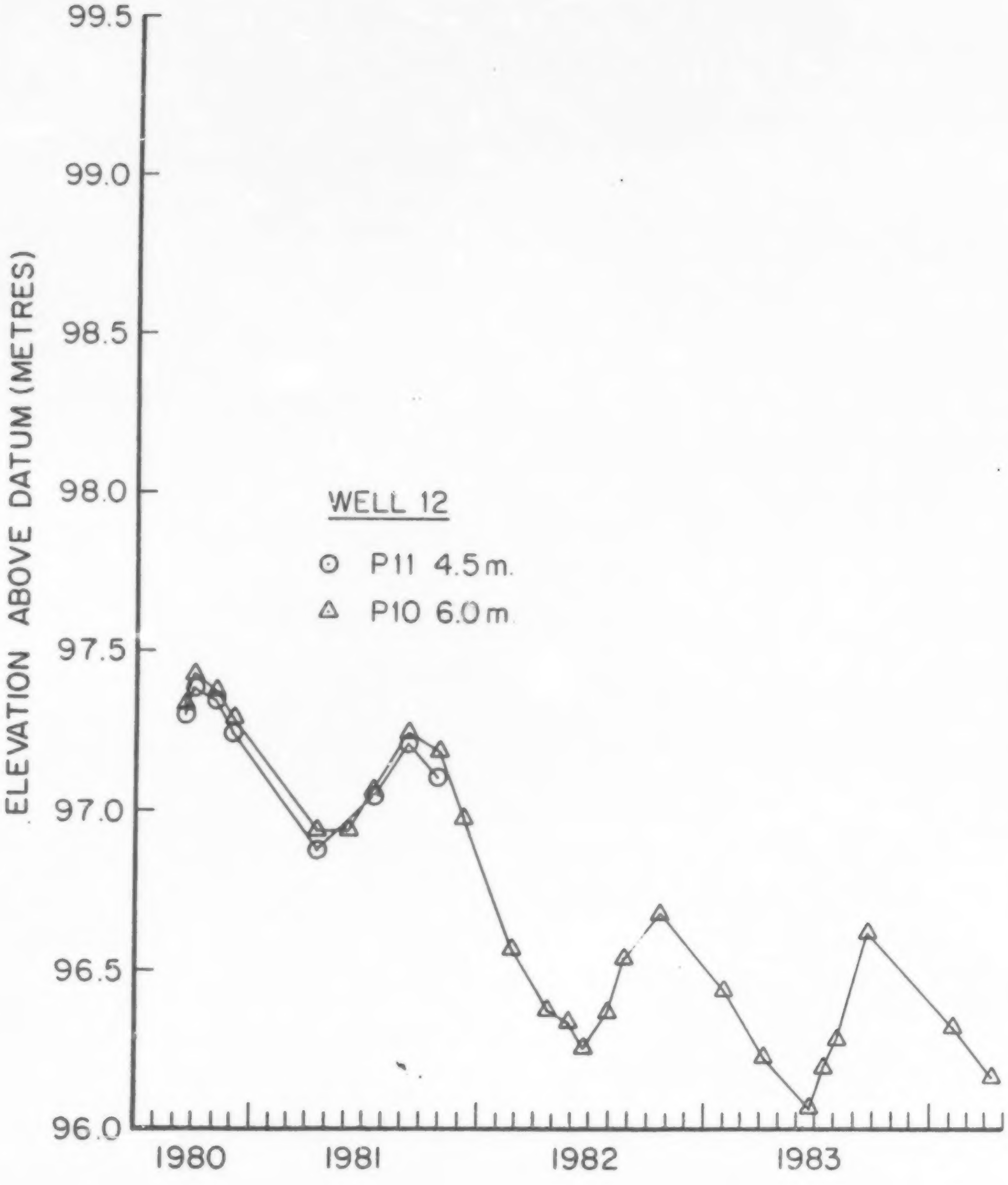
ELEVATION ABOVE DATUM (METRES)
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
1980
1981
1982
1983
WELL 12
⊙ P11 4.5m.
△ P10 6.0m.

FIGURE 2(d)

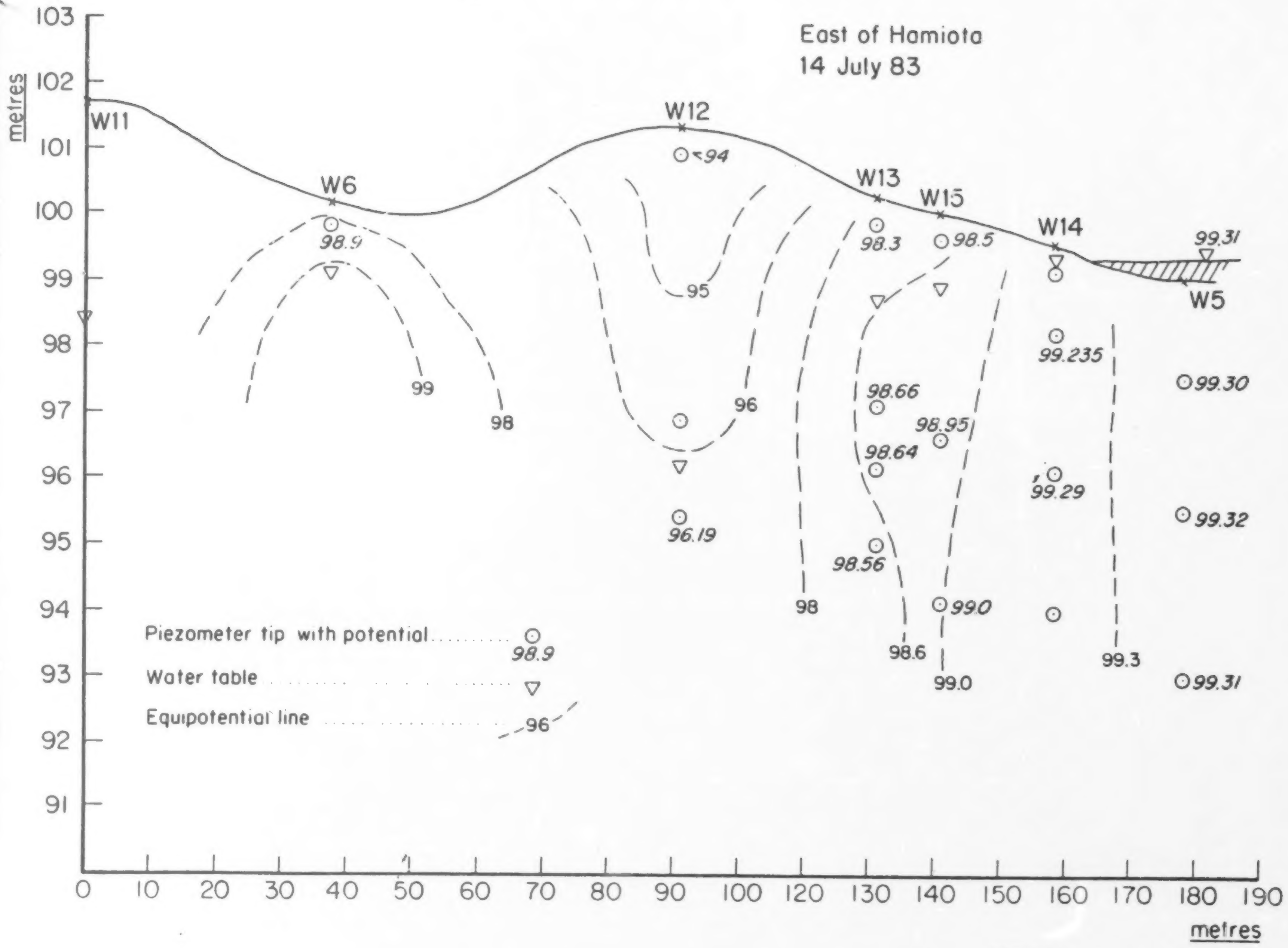
East of Hamiota
14 July 83
metres
103
102
101
100
99
98
97
96
95
94
93
92
91
W11
W6
W12
W13
W15
W14
W5
98.9
99
98
<94
95
96
96.19
98.3
98.5
98.66
98.64
98.95
98.56
98
98.6
99.0
99.0
99.235
99.29
99.3
99.31
99.30
99.32
99.31
Piezometer tip with potential
98.9
Water table
Equipotential line
96
0
10
20
30
40
50
60
70
80
90
100
120
130
140
150
160
170
180
190
metres

FIGURE 3

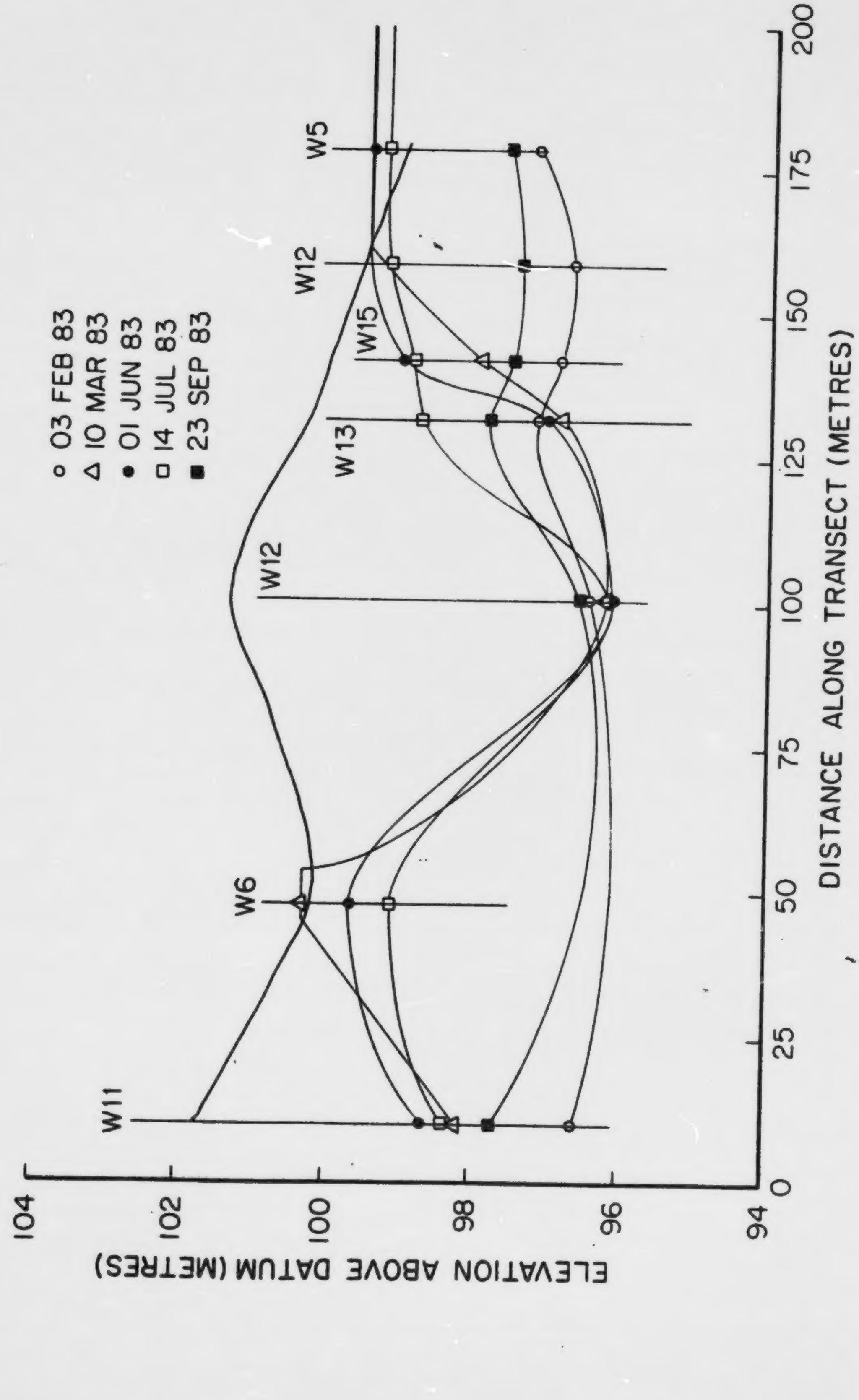
○ 03 FEB 83
△ 10 MAR 83
● 01 JUN 83
□ 14 JUL 83
■ 23 SEP 83
W11
W6
W12
W13
W15
W12
W5
ELEVATION ABOVE DATUM (METRES)
104
102
100
98
96
94
DISTANCE ALONG TRANSECT (METRES)
0
25
50
75
100
125
150
175
200

FIGURE 4

SATURATION AT 400.0 HOURS

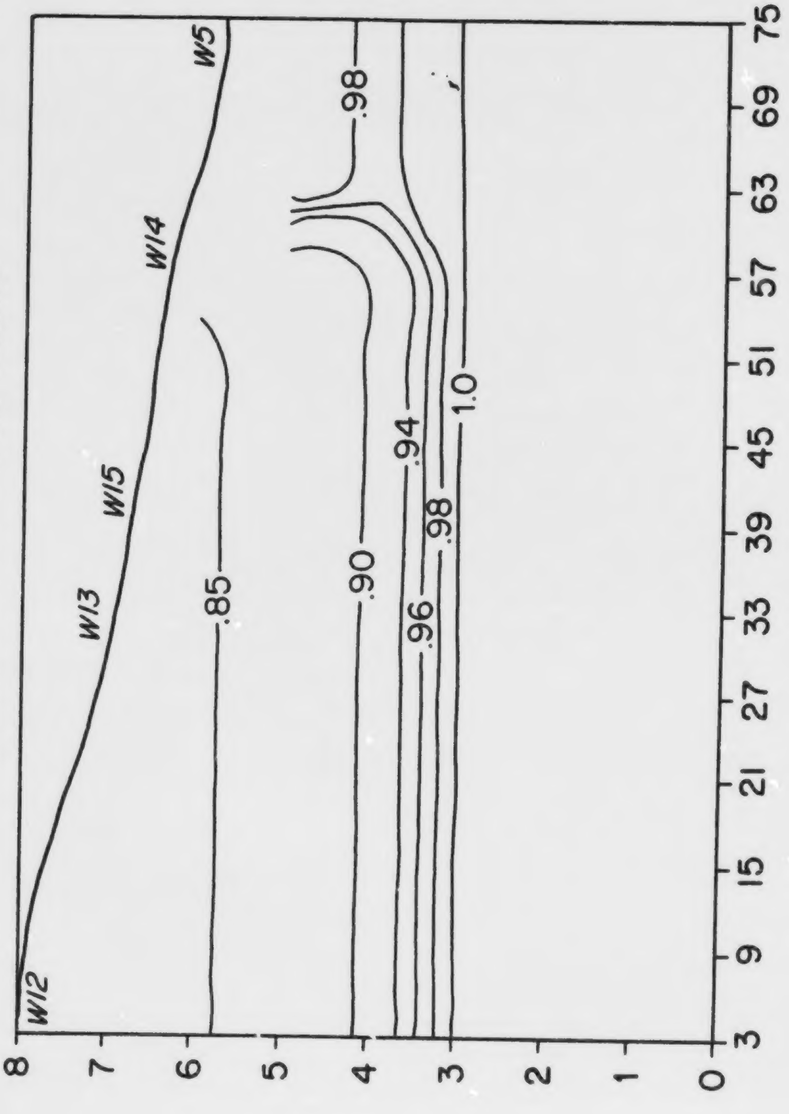

FIGURE 5(a)

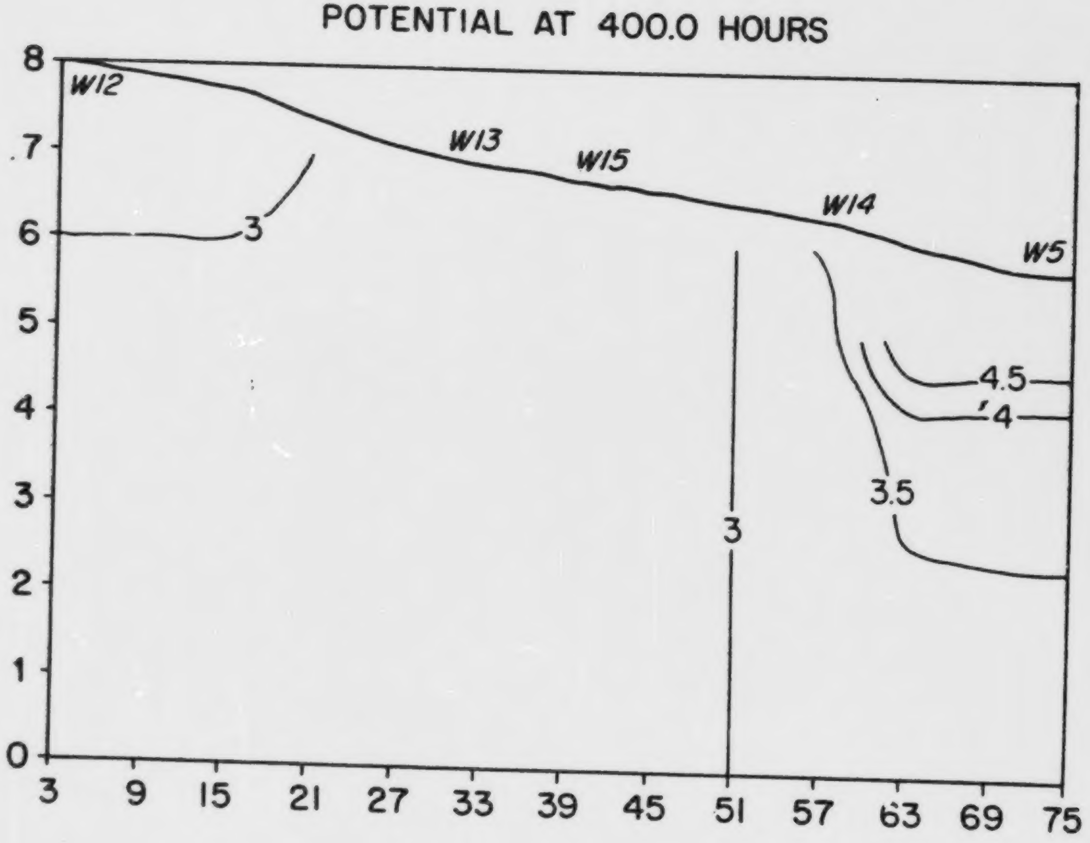
POTENTIAL AT 400.0 HOURS
8
7
6
5
4
3
2
1
0
3
9
15
21
27
33
39
45
51
57
63
69
75
W12
W13
W15
W14
W5
3
3
3.5
4
4.5

FIGURE 5(b)

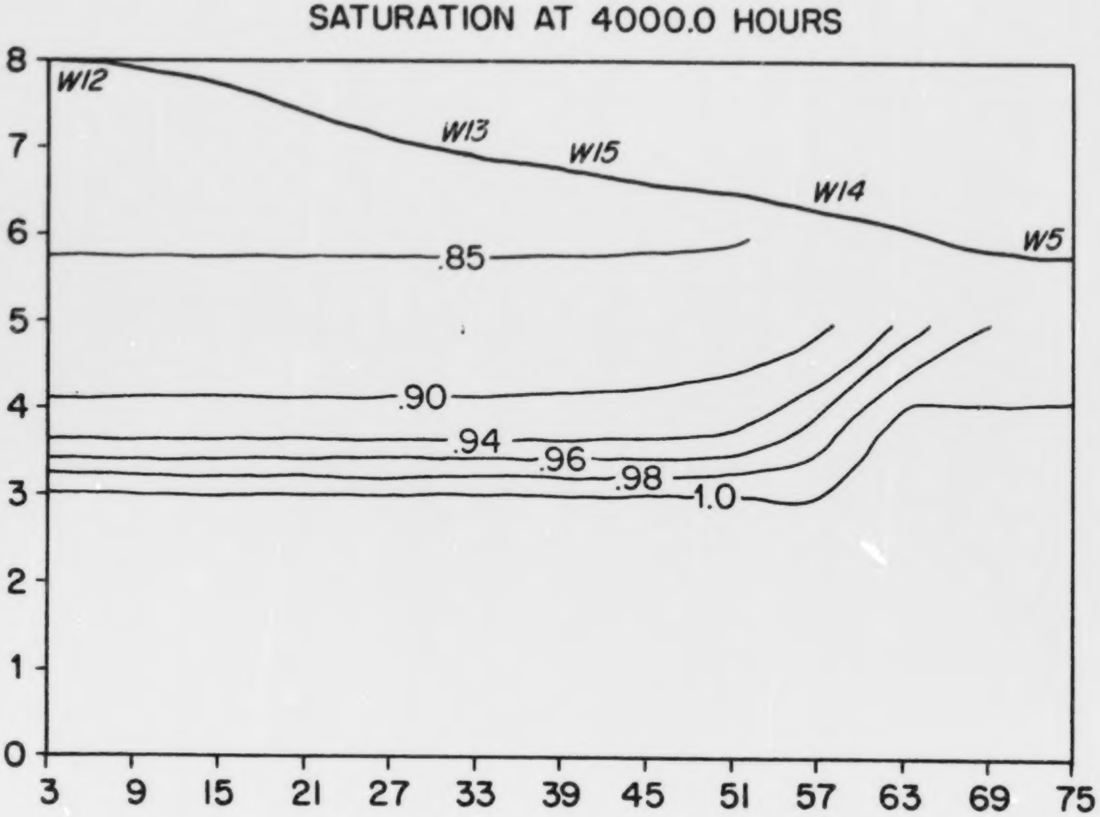
SATURATION AT 4000.0 HOURS

FIGURE 5(c)

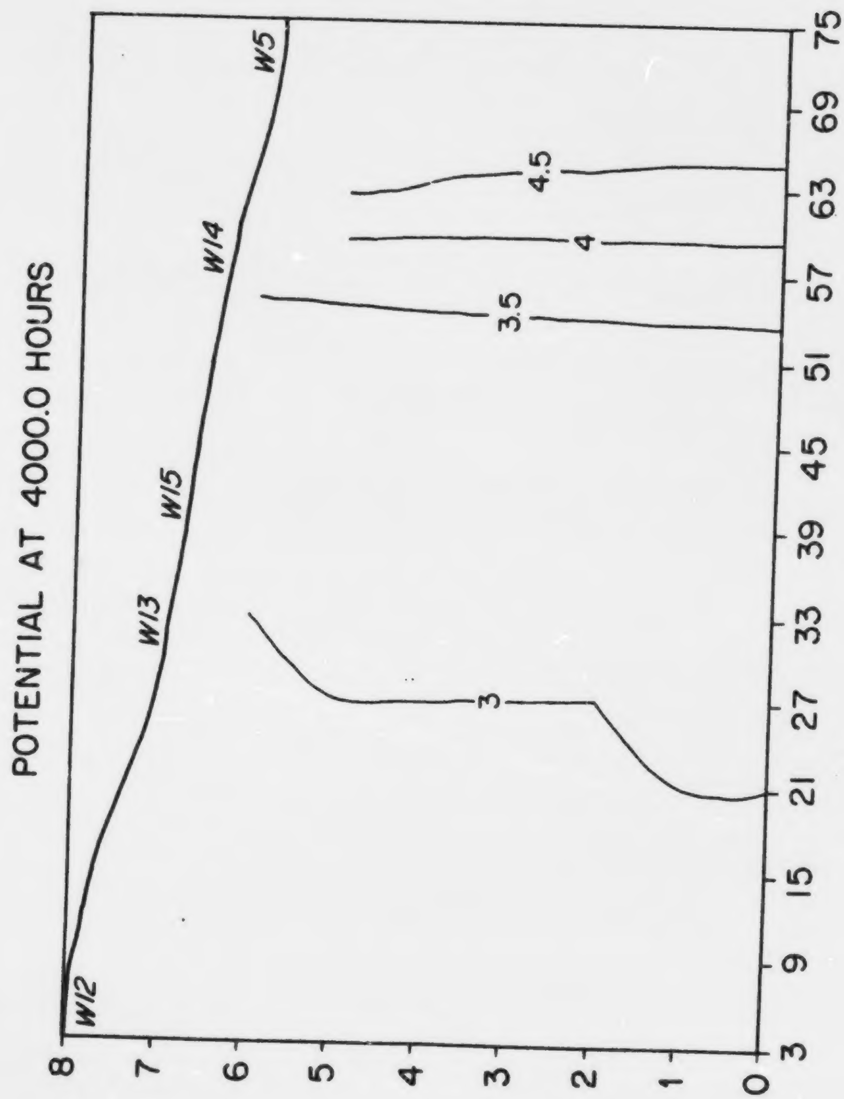
POTENTIAL AT 4000.0 HOURS
W12
W13
W15
W14
W5
3
3.5
4
4.5
0
1
2
3
4
5
6
7
8
3
9
15
21
27
33
39
45
51
57
63
69
75

FIGURE 5(d)

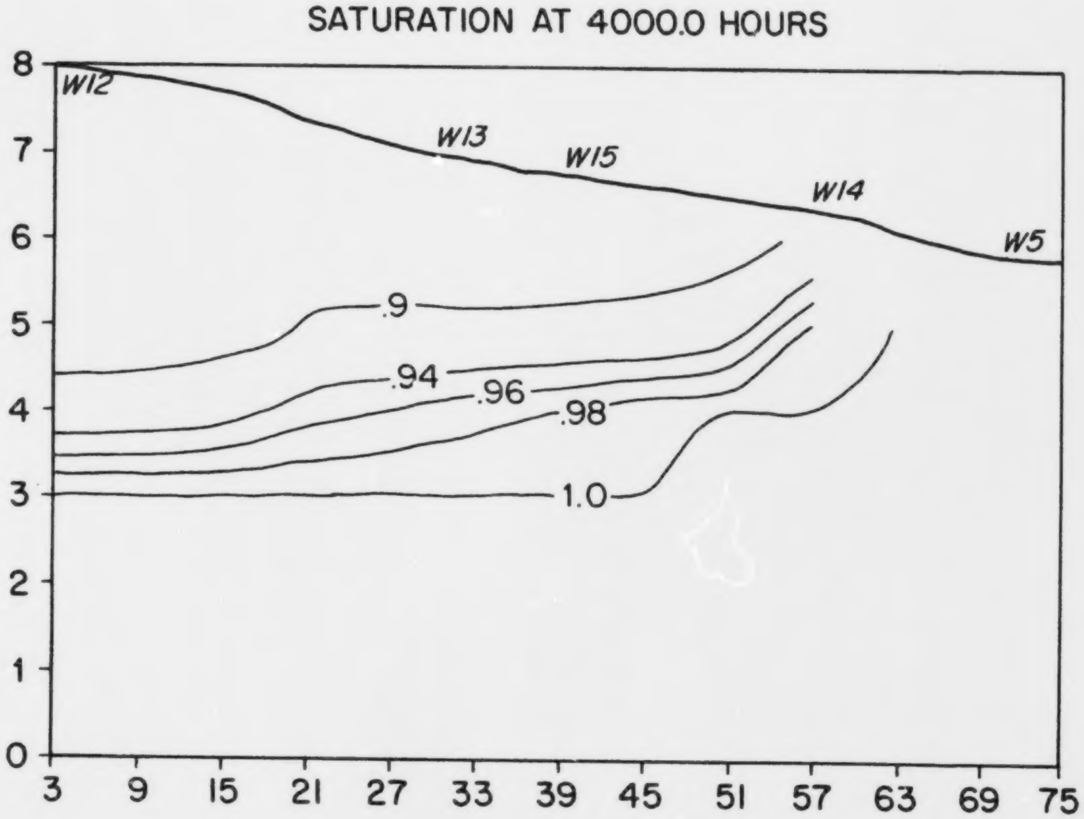
SATURATION AT 4000.0 HOURS
8
7
6
5
4
3
2
1
0
3
9
15
21
27
33
39
45
51
57
63
69
75
W12
W13
W15
W14
W5
.9
.94
.96
.98
1.0

FIGURE 5(e)

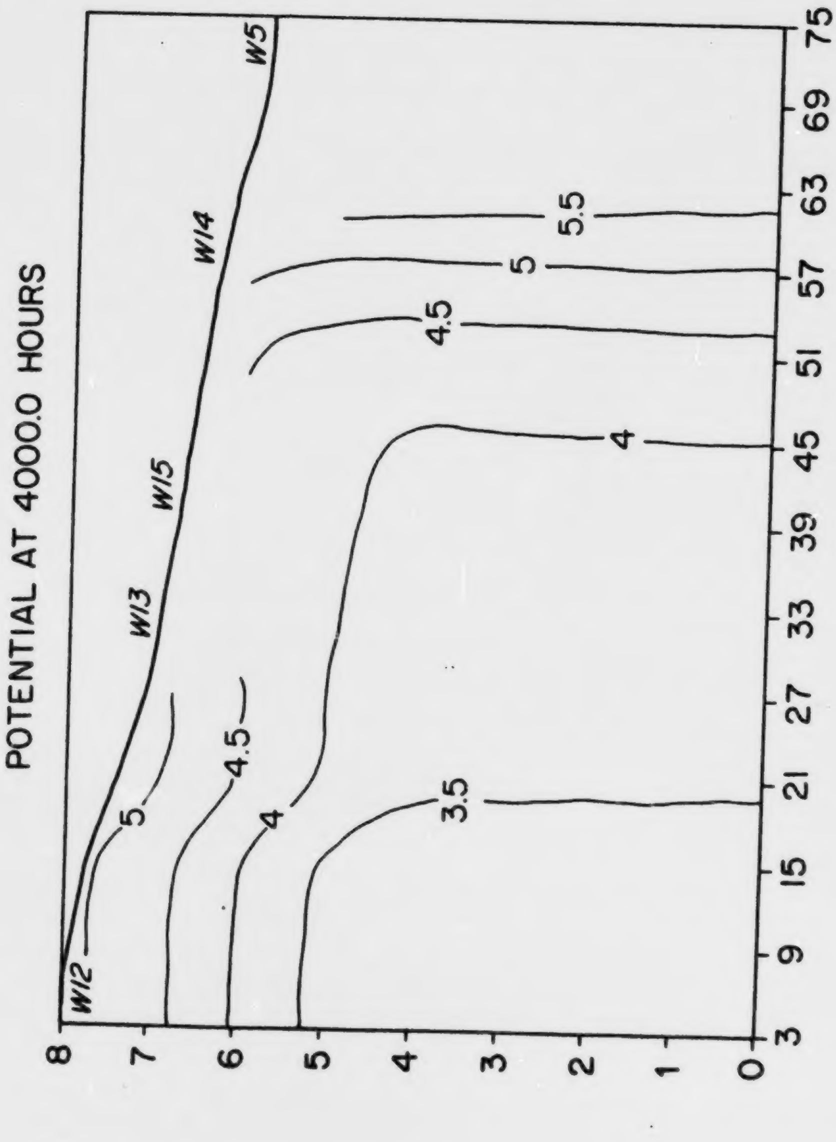
POTENTIAL AT 4000.0 HOURS

FIGURE 5(f)

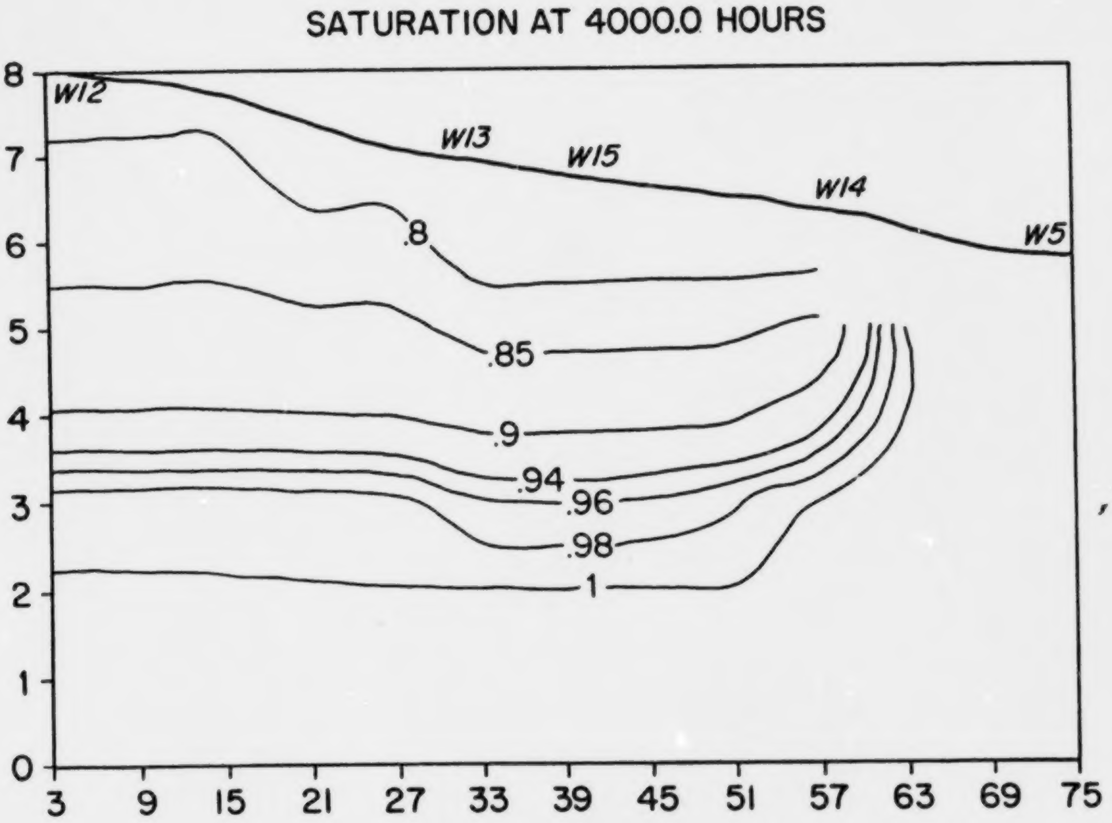
SATURATION AT 4000.0 HOURS
8
7
6
5
4
3
2
1
0
3
9
15
21
27
33
39
45
51
57
63
69
75
W12
W13
W15
W14
W5
.8
.85
.9
.94
.96
.98
1

FIGURE 5(g)

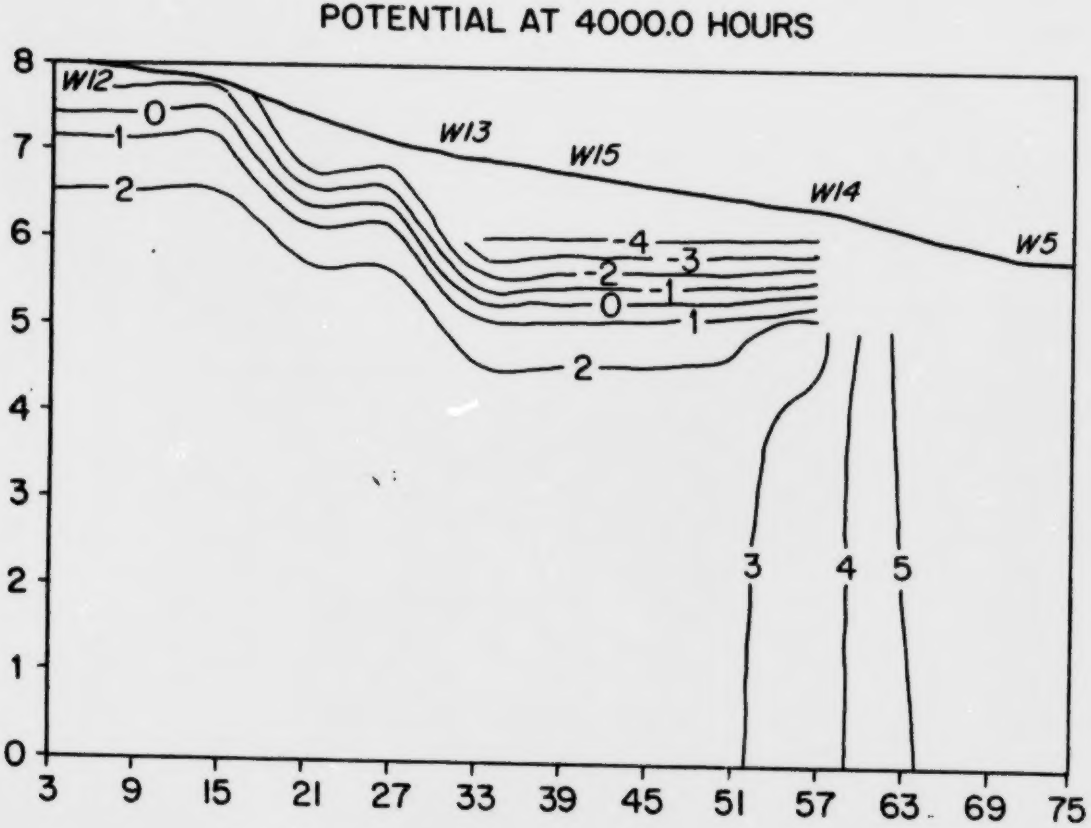
POTENTIAL AT 4000.0 HOURS
8
7
6
5
4
3
2
1
0
3
9
15
21
27
33
39
45
51
57
63
69
75
W12
W13
W15
W14
W5
0
1
2
-4
-3
-2
-1
0
1
2
3
4
5

FIGURE 5(h)

WARMER & DRIER THAN THE LAST 100 YEARS*

by

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Abstract

Carbon dioxide levels in the atmosphere are increasing due to the combustion of fossil fuels. This will inhibit the escape of heat from the earth, and by the middle of the next century, Prairie summers could be 3°C warmer and winters 5°C milder. The effect on moisture is complex to predict but some drying is possible in southern areas. The effects on present day agriculture will be mixed, but the opportunity exists to adjust in anticipation of a changing climate.

Paleoclimatology

Paleoclimatology allows us to look back a remarkable distance in time; it is estimated for example that there have been twenty-three major ice ages at very approximate intervals of 100,000 years. Figure 1 is an estimate of temperatures in four world areas during the last 100,000 years as implied from various sources. The agreement is clear as one sees the broad shape of the most recent ice age. Figure 2 illustrates the most recent 10,000 years which would include recorded history. Temperatures now appear to be similar to those at the time of the birth of Christ and in between is a cold period often referred to as the "little ice age".

Closer to home, Figure 3 is a composite trend of temperatures and precipitation at Regina, Saskatoon and Winnipeg since 1900, except that the period 1880 to 1890 is represented by Winnipeg alone. Ten year running means are used. Apparent is the rise in temperature of over 2°C from the beginning of the period to the 1930's; and an overall decline of 1°C from then until the early 70's. The magnitude and rate of these temperature changes is important for they form a basis for comparison with future estimations. Also clear from the graph is the inverse correlation of precipitation with temperature.

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* Also entitled "The Changing Prairie Climate: Problem or Opportunity?" and presented at the AIC, Hi-Tech Agriculture Conference, Winnipeg, August, 1984.

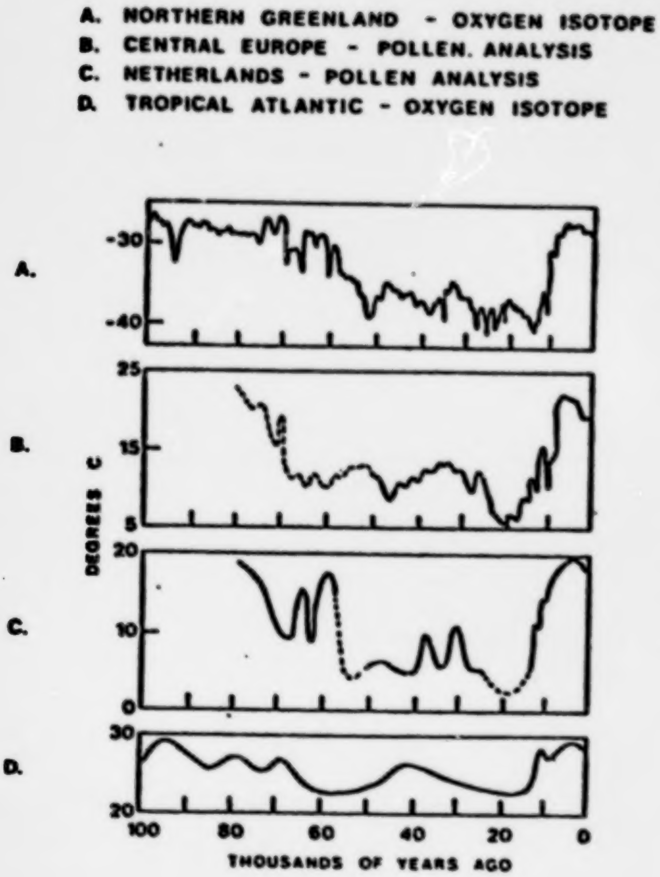

FIG. 1 WORLD TEMPERATURE OVER THE PAST 100,000 YEARS (from Hare)

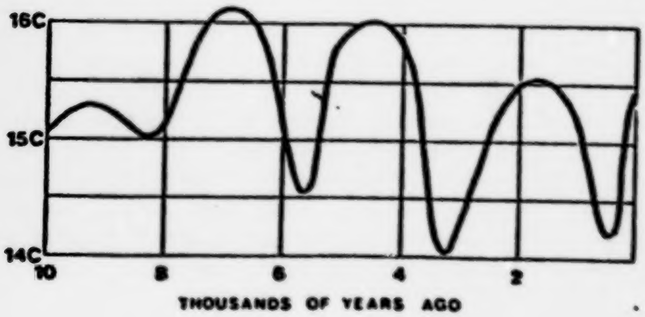

FIG. 2 WORLD TEMPERATURE OVER THE PAST 10,000 YEARS

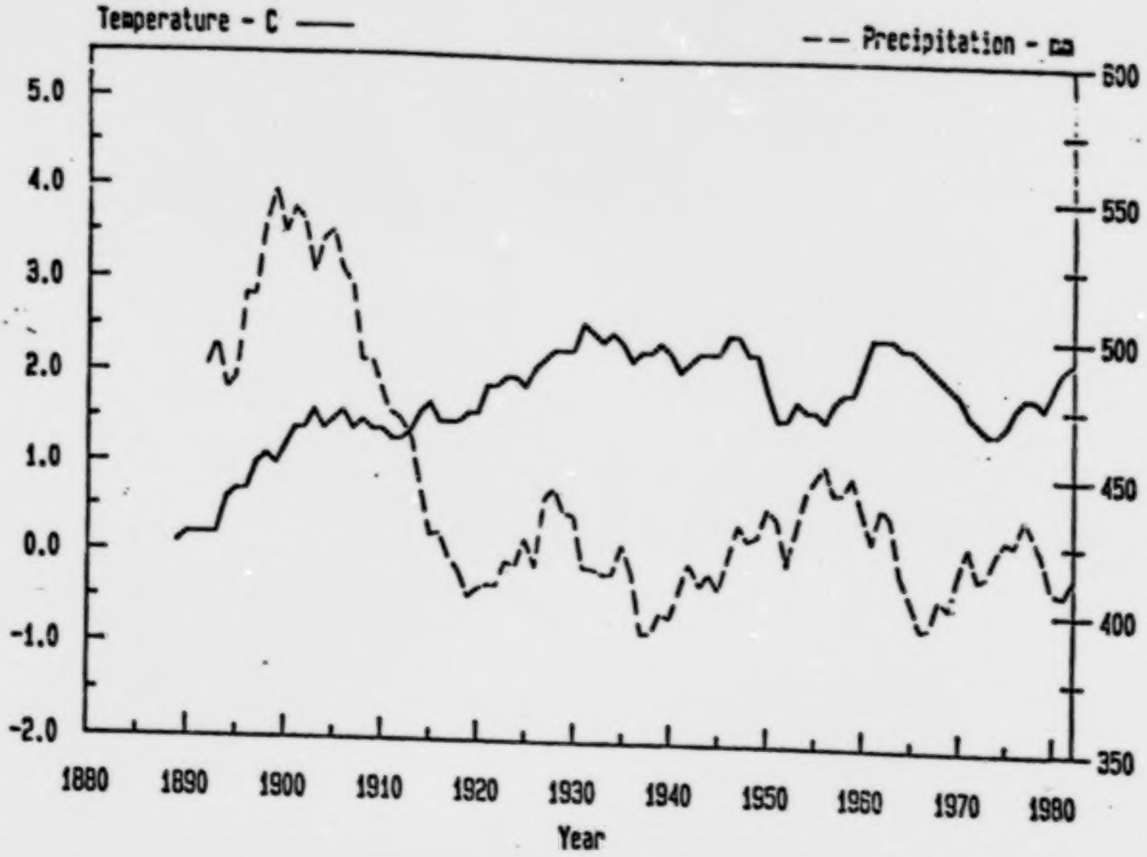

FIG. 3 CLIMATIC CONDITIONS - EASTERN PRAIRIES 1880-1982

The Causes of Climate Change

All of the energy to drive the earth's weather systems comes from the sun. Any variation in the sun's output, in the ability of the atmosphere to transmit that energy, or of the earth to absorb it, could alter the climate. Theories abound on these variations.

"Sunspots" may represent variations in solar output. Although specific measurement or theory relating energy reaching the earth to these transitory effects on the sun surface has been lacking (Landsberg, 1982), the cyclic nature of sun spots is temptingly regular. Many researchers have noted the apparent correlation between severe and variable weather and the "double sunspot cycle" of 22 years; the climatic extremes of the 30's, the 50's and the 70's are often cited as evidence.

One of the powerful theories is that originated by Milankovich in the 1920's and further developed by others, including Imbrie and Imbrie (1979). Sometimes referred to as the "stretch, wobble and roll" theory, it propounds that variations in the earth's axis of rotation and the shape of its revolution affect its distance from and aspect to the sun. The ability to make the necessary astronomical calculations far back in time facilitated its development.

Particles in the atmosphere reflect, or absorb and re-radiate some solar energy before it reaches the earth. This material includes wind-blown sand, dust, sea salt, smoke and volcanic debris. The last is the basis for another popular theory which relates aberrations in the climate to volcanic activity; it claims some support from apparent specific effects of history's more massive eruptions.

The earth itself is not entirely receptive to solar energy. It is estimated that 30% of incoming solar radiation is reflected by the earth's surface and changes in albedo caused by variations in ice and snow cover, deforestation, cultivation, desertification, etc. result in significant changes in the energy balance.

The foregoing theories have been presented in barest outline here and represent only the most common and most plausible of many speculations. They also represent natural processes and could almost without exception occur if man did not inhabit the earth; but man is not without his part in this affair. Every year we hurl deliberately or carelessly hundreds of millions of tons of waste particles and gases into the atmosphere.

The threat from gases is more serious in the present perception. Gaseous wastes from anthropogenic sources may not be greater than that from nature but are enough to cause an overloading, to total more than can be cycled harmlessly through the atmosphere. Emissions of sulphur dioxide and other oxides are leading to acid rain, which, if not global. in extent, is a very serious regional problem. A second and possibly more ominous manifestation is the atmospheric buildup of carbon dioxide

The records of atmospheric carbon dioxide are scattered and short; the best is that from Mauna Loa, Hawaii, since 1958 and it is shown along with other readings on Figure 4. The agreement is striking. Every available record demonstrates similar levels and a similar trend, indisputable evidence that the atmospheric concentration of carbon dioxide is rising. Processes, natural and man made, have been adding carbon dioxide at an increasing rate, which is now 3-4% per decade. The principal source is the burning of fossil fuels.

The mounting concentration of this gas is alarming because of the "greenhouse" effect. Radiation from the sun is of a short wave length and passes through the carbon dioxide in the atmosphere toward the earth; but counter radiation from the earth and clouds is of a much longer wave length and is impeded by carbon dioxide. The effect is reminiscent of a greenhouse (though it is not an apt analogy) preventing the escape of some of the earth's heat and resulting in a gradual warming.

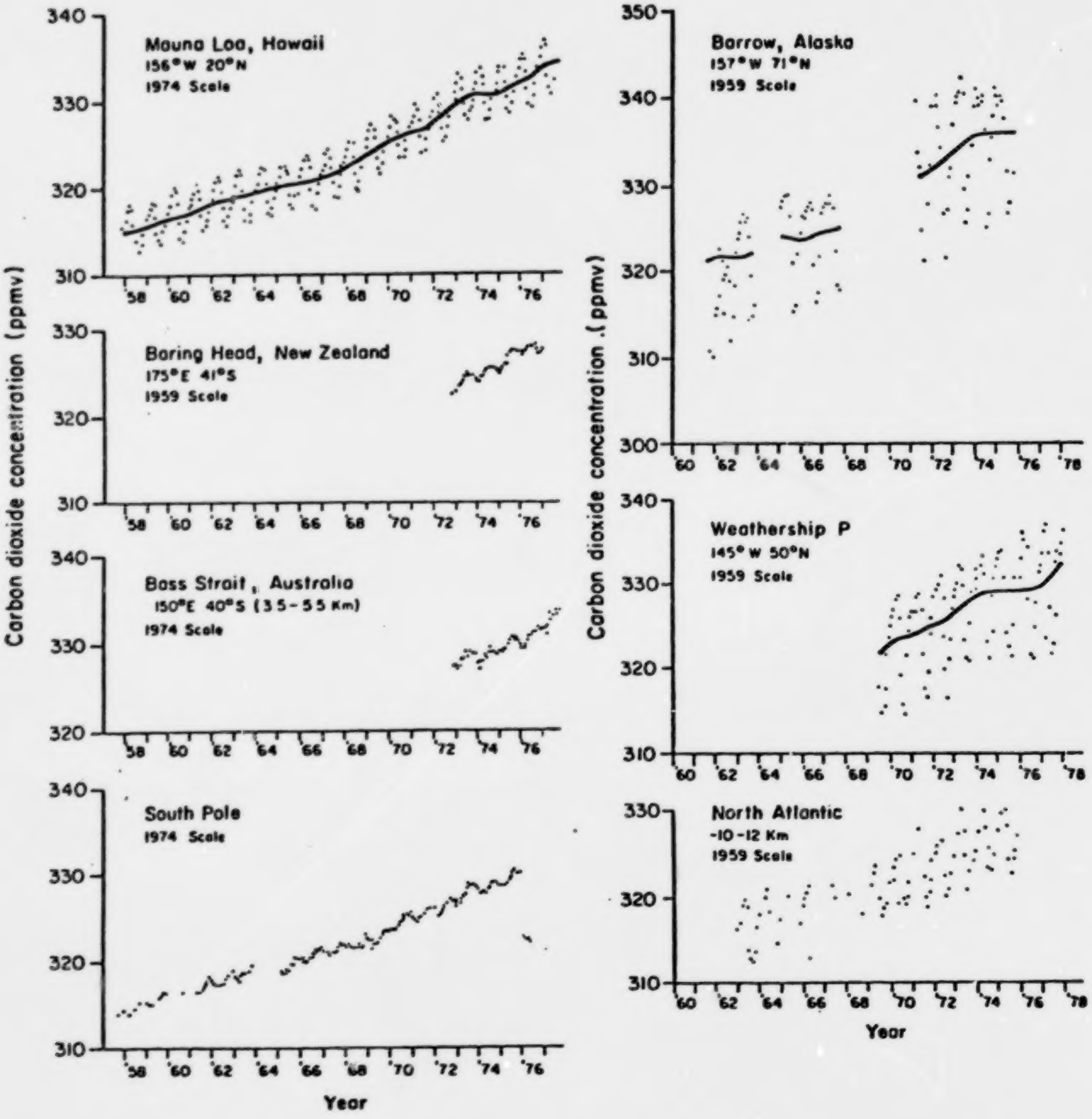

FIG. 4 TRENDS IN CONCENTRATION OF ATMOSPHERIC CO_2 — from Hare

A quantitative forecast of warming due to increasing carbon dioxide has been the object of intense climate research and the most convincing answers are those offered by simulations of the atmosphere referred to as global circulation models. Figure 5 represents the warming estimated by a number of these models for a doubling of CO2 from pre-1900 levels (Hare , 1979). Although there is considerable variation in the degree of warming predicted, there is clearly a concentration toward 3°C. In assessing the possibilities, the National Academy of Sciences of the U.S.A. in 1979 estimated the equilibrum global surface warming from a doubling of CO2 to be "near 3°C with a probable error of ± 1.5°C"; and in 1982 the National Research Council (U.S.) concluded that "no substantial revision of this conclusion is warranted at this time".

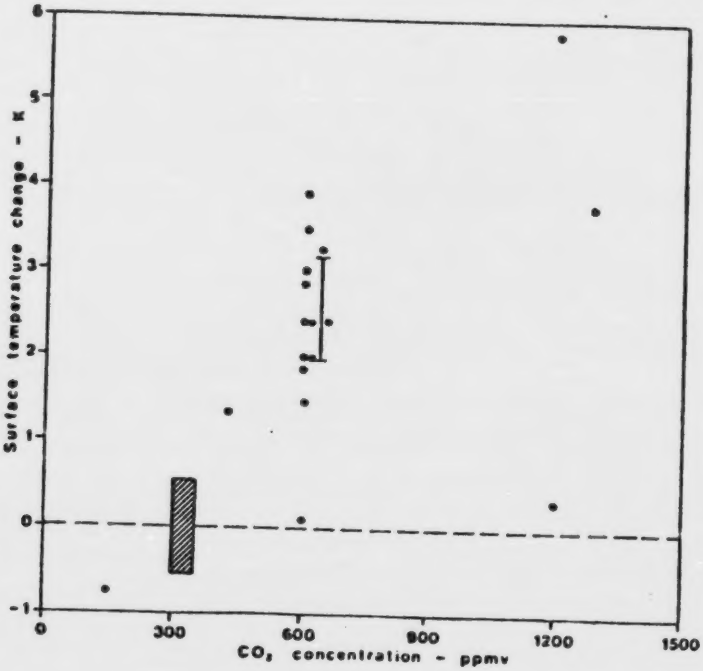

FIG. 5 MODEL CALCULATIONS OF TEMPERATURE WITH VARIOUS CO_2 CONCENTRATIONS (from Hare)

It is also likely that the effect is being increased by other trace gases. Oxides of nitrogen, chloroflouromethanes, hydrocarbons and carbon monoxide by themselves or through photochemical transformation also provide infrared absorption and may be adding as much as 50% to the carbon dioxide effect.

The time at which carbon dioxide doubling will occur is itself a point of much conjecture. The pessimistic view maintains that world trends in energy consumption will continue and that doubling will be realized in about 50 years. The optimistic view is that declining fossil fuel resources, increasing energy efficiency, alternate energies or other strategies will reduce the rate of increase and delay the doubling for at least 100 years. Recent events and attitudes, including the resurgence of coal and declining oil prices, produces some bias toward the pessimistic. All considered, an average global warming of 3°C by the year 2050 due to carbon dioxide and possible other trace gases seems plausible; this would be a world climate warmer than any since the dawn of recorded history.

A three degree warming would not be evenly distributed over the world; it would be somewhat less in the tropics and significantly higher toward the poles especially in winter. This is attributed to the positive feedback effect whereby the reduction of reflective snow and ice cover increases the solar radiation absorbed by the earth; this effect can be expected in countries with a significant snow cover season. A reasonable interpretation for the Prairies is that winters will be close to 5°C warmer than now, while summers will be nearer the 3°C average global warming.

Figures 6 and 7 display isopleths of mean monthly temperature in North America for January and July; the predicted warming is illustrated by employing five and three degree isopleths respectively. The suggestion is that the future temperature regime will resemble the present climate of the Dakotas and Montana.

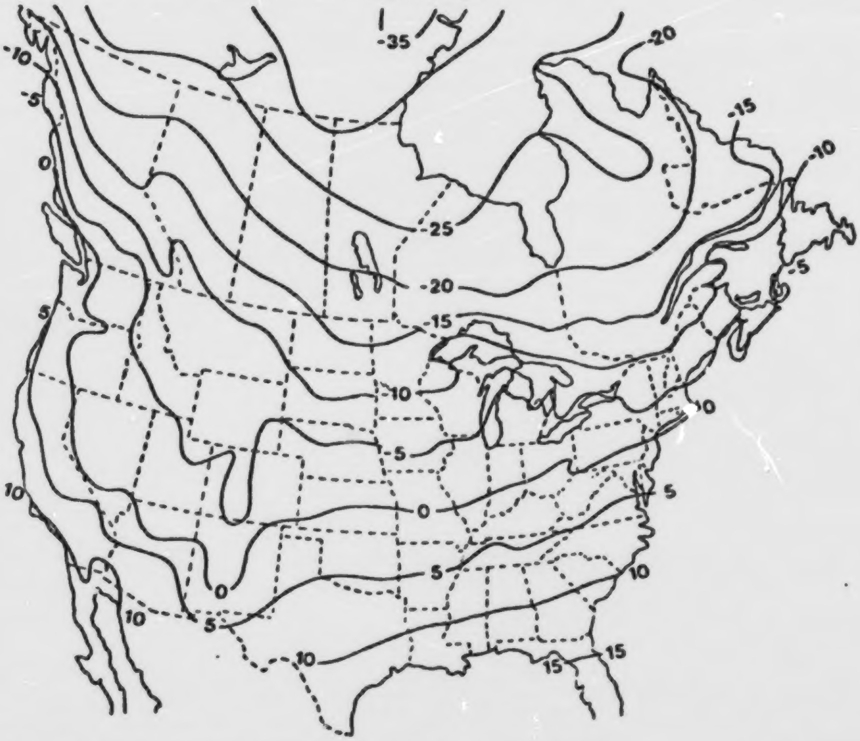

FIG. 6 MEAN JANUARY TEMPERATURES - °C. NORTH AMERICA

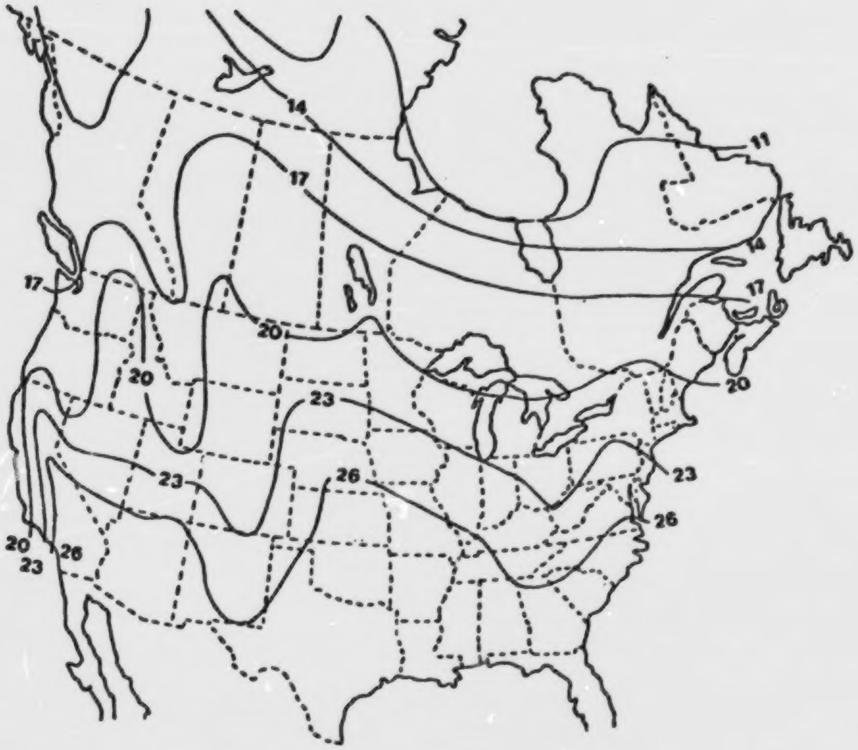

FIG. 7 MEAN JULY TEMPERATURES - °C. NORTH AMERICA

We cannot be as confident regarding moisture in a warmer climate. Higher temperatures would produce more evaporation from the oceans resulting on average in more precipitation world-wide; but again distribution would be uneven. The mountain masses of western North America would continue to inhibit the spread of moisture to the interior plains and the higher temperatures of those plains would increase evaporation from the land surface. The balance between these wetter/drier factors is a critical one which the models are not precise enough to determine with confidence.

The most useful information on moisture comes from the study of the climate of the Altithermal; this has been used by Kellogg and Schware (1982) to estimate probable soil moisture patterns on a warmer earth (Figure 8). The suggestion is that the central plains of North America will have lower soil moisture and although concentrated in the U.S.A. near 45°N some effect may be felt on the Canadian prairies. We should not attempt to read precision into such predictions; we should though realize that the odds in the Prairie Provinces favour drier rather than wetter, particularly in the southwest.

In brief summary the Prairie picture which emerges for 2050 is one of summers three degrees warmer than we now know them, and winter averages five degrees higher. Soil moisture will probably be reduced in the southwest.

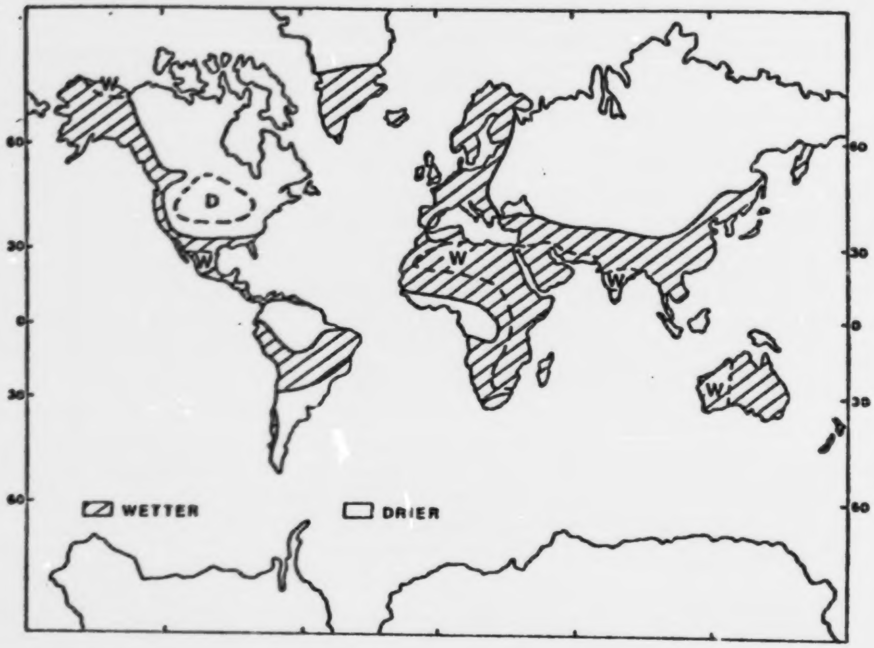

FIG. 8 SOIL MOISTURE PATTERNS ON A WARMER EARTH (from Kellogg and Schware)

Climate Change and Man's Activities

Canada's climate is one of extremes and social and economic activities have been carefully adjusted to those extremes, often pushed to the limit. The climate shift predicted would have widespread effects although not all undesirable; in fact in a land of harsh winters there is an instinctive feeling that warming would have more advantages than disadvantages. At the same time, we must focus on vital climate sensitive industries where the effect could be profound; the foremost of these is agriculture.

Agriculture

As a major export industry agriculture should be set in global perspective. Referring again to Figure 8 the estimate is that most world areas presently arid will enjoy higher soil moisture in the warmer regime, hopefully increasing their food production potential. In contrast, the current bread baskets of the U.S.S.R. and North America, including the Canadian plains, will suffer a moisture decrease which will impair productivity. Carl Butzer (1980) of the University of Chicago proposes that the net effect on world food supply would be decidedly negative and that the improved areas could not balance the losses in the productive zones. He notes that much corn acreage in the U.S.A. would shift to wheat which is of substantially lower productivity; while the shift of corn and wheat northward is limited by soil types.

Some estimates of impact now being developed by Williams (1983) suggest that on the southern prairies warming of 3°C and soil moisture reduction of 20% could reduce cereal crop yields by 10-20%. This does not, however, take into account possible adaptation by the agricultural industry.

Sylvan Wittwer (1980) of Michigan State University believes that agriculture can adapt with no loss of productivity. He cites the history of almost uninterrupted productivity increase in the face of climate trends very similar to those being predicted. The Canadian experience is similar but progress in the future may require more strenuous efforts than those in the past.

Another positive effect is that carbon dioxide is commonly a limit to photosynthesis and increased levels will enhance growth provided water, nutrients, heat and light are available. Supporting evidence for this effect is widespread as is its commercial exploitation in greenhouses; the outlook is only slightly clouded by the anticipation that for some plants initial enhancement may give way to a relapse in growth rate. Overall, Wittwer suggests that carbon dioxide enrichment could increase crop yeilds by as much as 20% by the end of this century if other inputs are not limiting.

An increase of mean temperature will significantly increase the length of the frost-free season; McKay and Allsopp (1981) suggest a lengthening of approximately ten days for a one degree mean temperature rise. This notable increase would be realized near the turn of century should the predicted warming occur, and on continuation the season will stretch 30 days by mid-century. A majority of the weather stations in the agricultural area of the Prairie Provinces now report frost-free seasons in excess of 90 days three years out of four; this probability could extend to 100 days by year 2000 and 120 days by 2050. As another measure of heat gain a three degree rise in summer temperature will add some 10% to the climatologically available growing degree days.

A potential disadvantage of a warmer atmosphere is an increase in agricultural pests and diseases. For example for some insects the longer and warmer season would increase the number of generations and multiply the control problem. Fortunately the record of improved control by chemical or other means is a good one and has made no small contribution to improved productivity over the years.

If soil moisture is in danger of being reduced so then are the other components of the hydrologic cycle including ground water, runoff and storage in water bodies. Some large systems which draw mainly on non-Prairie areas, would be least affected; the Saskatchewan River with its mountain sources is one example, while Lake Winnipeg is fed mostly by the Saskatchewan and by rivers originating in northwestern Ontario. The most vulnerable areas would be those relying on local supply, including a spring freshet that would have to last through a longer, hotter summer. Livestock operations in the south and west could be those most threatened by this water supply situation.

As previously mentioned, climatic capabilities for agriculture would be shifted northward into what are now temperature limited areas. The shift is clearly limited by soil types, but there are prospects of more viable agriculture in Manitoba's Interlake, in the northern Parkland in Saskatchewan, an in large areas of Alberta including the Peace River country.

On balance there is every reason for optimism. Benefical effects plus the demonstrated resiliance of agriculture should outweight negative features of the likely climate change. Certainly they will if the situation is recognized as a challenge and an opportunity not only to hold our own but to improve. They may not if we attempt instead to sustain the industry precisely as it is today and not seek ways to adjust.

Reaction and Adjustment

It is the task of Climatologists to continue their earnest research into carbon dioxide and climate change until the evidence is clear and the change quantified. This may take twenty years. In the meantime, it is unrealistic to expect that there will be a massive effort to adapt agriculture or for that matter other industries in other parts of the world. If we do nothing, however, we may find ourselves in an unfavourable catch-up position. What is needed is a strategy that offers every chance of success without heavy demands on the purse. Such a strategy exists; its mainstay is selective research based on existing strengths and directed at critical climate impact areas.

Research in agrometeorology and hydrometeorology are well established on the Prairies and have impressive records of success. With even a partial redirection and modest increases in resources much can be done to put us in a more favourable position. When that is recognized some priority research areas might include the performance of plants under carbon dioxide enrichment; inhibition of evaporation through techniques such as minimum tillage; the viability of crops with greater heat requirements; expanded water storage; and water conservation.

Thrusts such as the foregoing are particularly attractive in that they will yield benefits whether or not a significant change in climate occurs. This probability exists precisely because of the long standing recognition of the relationship between climate and activities in Canada and the existance of mechanisms directed at optimizing that relationship.

Summary

That the concentration of carbon dioxide is increasing cannot be doubted. The overwhelming body of scientific opinion is that it will alter world climate and the best estimates available for the Prairies are that the climate will be warmer than at present while soil moisture might well decrease particularly in the southwest. The impact on agriculture could be severe if a blind eye is turned to the possibility of such change. A program to augment existing strengths in agrometeorology and water management could be undertaken at relatively little cost and with the prospect of high pay-off; properly pursued it could place the Prairie Provinces in an advantageous position and is an opportunity which should be grasped.

References

1. Butzer, Karl W., 1980: Adaptation to Global Environmental Change; Professional Geographer 32(3), 1980.

2. Climate Research Board, 1979: Carbon Dioxide and Climate: A Scientific Assessment; National Academy Sciences, Washington, D.C.

3. Climate Review Panel 1982: Carbon Dioxide and Climate: A Second Assessment; National Research Council (U.S.), Washington, D.C.

4. Hare, F.K., 1981: The Carbon Dioxide Question: Canadian Perspectives; Atmospheric Environment Service, Downsview, Ontario.

5. Imbrie, J., and Imbrie, K.P., 1979: Ice Ageo-Solving the Mystery; Enslow Publishers, Short Hills, N.J., 224 pp.

6. Kellogg, W.W. and Schware, R., 1982: Society, Science and Climate Change; Foreign Affairs, Summer 1982.

7. Landsberg, H.E., 1982: Solar Variability, Weather and Climate; National Weather Digest, Vol. 7, No. 4.

8. Manabe, Syerkuro and Stouffer, Ronald J., 1980: Sensitivity of A Global Climate Model to an Increase of CO2 concentration in the Atmosphere; Journal of Geophysical Research, 85(C10).

9. McKay, G.A. and Allsopp, T., 1981: Climate Change and Energy Use: A Northern Perspective; Atmospheric Environment Service, Downsview, Ontario.

10. Pollard, D.F.W., 1981: The Global Carbon Dioxide Issue: A Perspective for Forestry in Canada; Pacific Forest Research Centre, Victoria.

11. Rodin, L.E., Bazilevich, N.I., and Rozov, N.N., 1975: Production of World Ecosystems; National Academy of Science, Washington.

12. Williams, C.D.V., 1983: unpublished; Atmospheric Environment Service, Downsview, Ontario.

13. Wittwer, Sylvan H., 1980: Carbon Dioxide and Climate Change: An Agricultural Perspective; Journal of Soil and Water Conservation, Vol. 35, No. 3, May-June 1980.

HYDROGEOLOGIC STUDIES FOR THE IDENTIFICATION AND CONTROL OF DETRIMENTAL CANAL SEEPAGE IN SOUTHERN ALBERTA

J. T. FORSTER

In outlining investigative procedures pertaining to the identification and control of canal seepage, I will, for this presentation, be referring primarily to a system designed to carry in excess of a 1000 c.f.s. flow. The procedures discussed will relate to those employed by the Department of Environment in rehabilitation and expansion of the Lethbridge Northern Irrigation District's main supply canal. This system is an 80 km stretch of canal diverting water from a diversion structure on the Oldman River west of Fort Macleod to an onstream storage reservoir located just north of Lethbridge, Alberta.

To effectively define seepage control requirements for a specific reach of canal, it has been the policy of this Department to commence such an investigation with a preliminary office evaluation. This initial office assessment usually includes:

1. An Analysis of Air Photo Coverage

Any available air photo coverage of the immediate project area is collected and evaluated as to its potential use in the study. This coverage can be at a variety of scales, under various photo spectrums, and spanning a significant period of time. If no recent low level air photo coverage is available, a request is usually filed to have this additional coverage provided.

For canal systems that are already in existence and in the process of being either upgraded or rehabilitated, as is the case with this system, it is often useful to compare photo coverage taken prior to initial construction or in early stages of operation with coverage obtained for a period much later in the operating history of the facility. This comparison can often help differentiate areas influenced by natural discharge from areas obviously affected by canal induced discharge. Such coverage also helps to establish the aerial extent for which further detailed field investigation may be required.

We have also found that the use of infrared photography can be extremely useful in delineating possible areas of canal induced discharge problems. This has proven particularly true if the system being investigated transects a region of dryland production and coverage is available for a period when normal soil moisture has been depleted but crop growth is still underway.

Use of low level (1:5,000 - 1:20,000) stereoscopic airphoto coverage is also extremely useful in the early stages of investigation to assist in defining such features as:

- local land forms
- surficial drainage patterns
- general topographic relief, and
- farming and cropping patterns of the region.

All the above features are relevant to determining what degree of field investigation may be required in subsequent stages of investigation.

The low level airphoto coverage also provides the base for preparation of topographic contour plotting inputs and preparation of base mosaics utilized in the actual report preparation.

2. Review of Available Resource Reports

The review of published resource information such as soil survey reports, surficial geology reports, general bedrock and hydrogeologic mapping, agricultural land capability assessments etc., available for the area concerned is always important. This information while never available to a sufficient level of detail for specific recommendations on seepage control measures to be made, it does provide a necessary base from which requirements for supplemental field investigation can be assessed. Some specific instances as to how such information can provide substantial insight to subsequent field studies would be:

- Surficial geology reports can help identify areas of similar geology and thus provide some assistance in evaluating needs for geologic coring intensity, types and locations where specialized drilling equipment may be necessary and generally providing insight into the susceptibility of a given area to problems of excessive seepage loss or sensitivity to problems of surface soils salinization.
- Soil and agricultural capability information can help differentiate general regions of high and low agricultural productivity, areas of low water holding capacity or high permeability, areas of restricted internal drainage, and areas subject to natural groundwater discharge. All information useful in assessing the need for seepage protection within a given location.
- Information from geologic and hydrogeologic mapping can assist in determining areas of shallow bedrock or an impeding groundwater flow interface, thus resulting in a high potential for seepage damage and the need for intensive or specialized field investigation.

3. Compilation of Meteorological and Irrigation Flow Records

Data specific to certain meteorological parameters and canal flow records have proven particularly useful for assessing impacts of canal seepage losses on the local groundwater system. Therefore, as part of our initial office evaluation, we review precipitation records of the past 5 year period in an effort to delineate any trends that may show up or help explain results of specific groundwater monitoring conducted later in our investigative program.

Records from any gauging stations or check structures along existing conveyance facilities in the study region are reviewed and used to assess where supplemental monitoring stations may be necessary or where within the region a potential for excessive seepage loss appears to exist.

On completion of the office evaluation which is usually accomplished within the initial month of the project assignment, we reach the stage where layout of a field investigation program takes place. Due to time constraints associated with most of these project assignments, it is vital that most of the required drill testing and instrumentation be undertaken early in the field investigation program. This leaves little opportunity for pretesting and requires that any need for groundwater instrumentation be determined during the drilling process and installed at that time. In most cases, the field investigation is restricted to within half a mile on either side of the proposed canal centerline. Exceptions to this being areas where air photo coverage, farmer complaints or field inspection indicate an apparent problem of canal induced seepage damage. For most projects centerline drilling is conducted at 50 meter intervals along the proposed alignment under consideration. Cross-sectional transects of a similar drill spacing at right angles to the proposed canal alignment are also conducted at mile intervals or at locations where centerline drilling indicate a potential for a canal seepage problem to occur. Depending on the presence or absence of a groundwater table within the test zone, additional groundwater instrumentation may also be recommended at these test sites.

Once a field testing program has been determined for a given reach of canal, specific landowners along the proposed alignment are approached. The need for the investigative program is discussed with them, information is solicited as to any aspect of the development that may concern them and an agreement established with them to enable us to enter onto their property for the purpose of installing and monitoring any instrumentation or drilling sites as may be required.

Some specifics as to the actual field testing program employed in our seepage investigation program would be a follows:

1. Test Drilling

Test drilling is conducted to document and map the geologic lithology of the region and determine where, if applicable, supplemental groundwater instrumentation is required. The drilling is usually completed utilizing the departments B40-L mobile auger drill. This rig primarily employs a push-pull sampling technique utilizing approximately 10 cm O.D. hollow core augers in which the augers are screwed directly into the surficial soil materials and hydraulicly extracted to enable description and sampling of the auger cuttings. The rig is also equipped to perform continuous split spoon coring, utilizing a combination of 18 cm O.D. hollow stem augers and 6.4 cm split spoon core barrels. Continuous coring is usually conducted at a number of strategic locations within regions of specific geologic composition. The intent of the split spoon core sampling being primarily to characterize, in greater detail, the nature of the surficial materials and to supplement logging detail as provided by the auger drilling technique. For deeper testing and drilling in consolidated bedrock deposits the 10 cm O.D. augers are utilized in conjunction with compressed air jetted through the drill bits. This enables drilling within the harder bedrock deposits and allows cuttings to be blown to the surface, relatively intact, enabling bedding sequence and general physical composition of these deposits to be determined. On occasion supplemental test trenches are also excavated within the bedrock deposits to assist in establishing the degree of fracturing that may exist in the upper bedding and the ease of excavation of these materials for geotechnical consideration. The use of auger style drill rigs for this type of work has proven to be extremely successful and utilized for almost all our drilling needs. The only situation in which these rigs do not function effectively are in coarse or soupy outwash deposits and in these cases we have had to contract the work out to a private firm with a hammer drill unit.

Soil profile features are characterized from the drilling records and soil textures logged utilizing standard soil terminology. In the case of our investigation the U.S.D.A. system of textural classification is used as it is felt it provides the widest scope for interpretation of hydraulic behavior of unconsolidated geologic materials. Other geologic features such as the geologic origin of the surficial soil materials, soil densities, micro structure, presence or absence of secondary salt enrichment, depth of salt and carbonate leaching, general soil coloration, soil moisture status, depth of bedrock contact, and geologic characteristic of the bedrock lithology are all noted. As well representative soil and bedrock core samples are selected and analyzed to establish parameters such as particle size distribution and overall chemical composition.

2. Shallow Groundwater Instrumentation

In addition to the test drilling directed at characterizing the basic soil and geological lithology of the region, an instrumentation program designed to establish the general nature of the shallow groundwater flow system for the study region is also implemented. This portion of the study includes the installation of a network of water table wells (W.T.W.) and piezometers aimed at categorizing the general direction and gradients of groundwater movement. Placement of the instrumentation is structured such that naturally occurring and possibly canal induced groundwater patterns can be evaluated. This includes placement of instrumentation within direct vicinity of the preferred canal centerline alignment and where possible at right angles to both the upstream and downstream sides of the proposed canal routing.

Water table well standpipes are placed within the upper confined soil zone utilizing accepted field instrumentation techniques as outlined in Winger and Luthin's Guide for Investigation of Subsurface Drainage Problems, Special Publication SD-04-66.* Piezometers designed to monitor a specific conducting zone are installed at deeper depths in apparent confined or semi-confined aquifers to identify major zones of water movement and to help establish general flow direction and gradients by which the shallow groundwater travels. Certain aspects of the groundwater flow regime such as relevant surface groundwater contour data, upward or downward flow potentials and general flow gradients can be established shortly after installation and stabilization of the groundwater instrumentation. Other important time related flow variables, however, such as seasonal flow patterns, response behavior to certain hydrologic or canal induced event, etc., require that a series of measurements be completed over a relevant span in time and thus the establishment of a specific monitoring schedule.

In general, test drilling and shallow groundwater instrumentation procedures are completed within a 4 to 6 month period from commencement of the field investigation program. Subsequent to this, a regular monthly monitoring schedule is implemented in which the instrumentation is read at regular monthly intervals for at least the duration of a 12 month period. Information gained from the monitoring of such groundwater instrumentation can help determine if high groundwater tables occurring within the proposed canal cross-section, are largely induced from canal related seepage or the result of natural groundwater discharge in the region and provide insight into how far out from the canal water tables may be influenced by fluctuations in canal flows and how quickly such fluctuations influence water table levels of the surrounding areas.

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* American Society of Ag. Eng.

During the period in which regular monthly monitoring data is being collected for the study area a number of supplemental test procedures are also undertaken. These specialized test procedures are intended to provide information on the relative permeability or hydraulic conductivities of the various geologic materials identified in the initial field drilling program. These tests vary depending on whether or not saturated conditions exist within the zone of interest. For zones in which there is no existing groundwater table we usually perform either a well permeameter test or ring infiltration test. In zones where saturated water table conditions exist we generally conduct either a formal pump test or single well response tests.

Once information relevant to all the geologic and shallow groundwater studies have been compiled, a framework is established whereby consideration of a number of the following items can be made:

- what degree of seepage loss can be anticipated within this given sector of canal?
- what influence will such seepage losses have on the agricultural potential of adjacent land areas?
- what geologic or groundwater parameters will influence the type of seepage control measures that can be considered for controlling an identified seepage problem?
- are the groundwater conditions noted the result of high natural discharge levels in the reach or created solely as a result of residual groundwater buildup from an existing seepage facility?
- will seepage losses be dissipated through deep percolation losses or primarily move laterally affecting low lying or downslope areas bordering the proposed canal facility?

- is the problem confined to a specific region within the study area or interspersed throughout the entire study section?

All these factors then relate to the decision made as to where seepage control measures are required and what types of control measures will be most suited to control of the specific seepage problem defined.

In Summary

The test procedures we employ have proven to greatly assist in determining if and where seepage control measures will be required, what type of control measures will be most effective in controlling such problems and what design parameters will have to be employed in installation of these controls to insure such recommended control measures are effective in handling the defined problems. There is no doubt a need to modify and refine many of the test procedures however as more of these types of studies are undertaken.

Results of our studies indicate that geologic and hydrogeologic conditions will vary along a given system and the needs for seepage control will depend on our ability to identify and describe these changes. It is hoped as more of this rehabilitation work is completed that even greater refinements in investigative methology can be achieved. What certainly has been established from our work here in Alberta is that lining these large conveyance canals with flexible PVC liners is a feasible seepage control measure and that the use of cutoff curtains and interceptor drains continue to be viable alternatives for controlling seepage problems under certain hydrogeologic conditions.

SESSION III

Engineering and Economics

Session Chairman: L. J. Whitney

Legislation and Policies
related to
Agricultural land Drainage in Saskatchewan

Presented by: L.A. (Lee) Gatin
Watershed Administration Manager
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Presented to: Conference on Agricultural Land Drainage
Winnipeg, Manitoba. November 20-22, 1984

Many people think of Saskatchewan as being a vast, drought stricken area where farmers have developed hereditary crinkles in the corners of their eyes from constantly looking at the bright sky in search of rain clouds and where the citizens have never learned the knack of spitting because it is so dry, they have no saliva. It is certainly true that in some years, in some parts of the province, drought is experienced and the lack of water causes severe problems. But, much of Saskatchewan's topography is comprised of prairie pot-holes and sloughs and the soil texture is a heavy clay. To the farmers in those areas, flooding is as great a concern as drought. The area in particular lies north-east of a line drawn from the City of Weyburn in the south-east corner of the province to the City of Lloydminster located in the north-west.

Drainage has played an important role towards the development of Saskatchewan's agricultural resource base, particularly in new settlement areas opened during the post war period. In more recent years, farmers have increased drainage activities to increase productivity and to off-set higher land costs and higher operating costs and to make more efficient use of large farm machinery.

What I will talk about today is the regulatory aspects of agricultural drainage, and the legislation by which Saskatchewan is attempting to regulate and control drainage activities. Also, I will briefly outline policy guidelines which are used to assist in approving or denying drainage approval applications.

Legislation Relating to Drainage

Prior to 1981, no legislation existed in Saskatchewan which was specifically designed to regulate and control drainage development. While Saskatchewan has had The Water Rights Act since the federal government transferred the responsibility for water resource management to the province in the early 1930's, that Act was specifically designed to regulate the use of a scarce water resource through a process of allocation and licensing, but not to regulate the removal of surface water from land.

Several pieces of legislation exist which enable individuals, groups, municipalities and government departments and agencies to construct drainage works, but, until 1981, there was no legal requirement for those drainage works to be approved by some central authority prior to their construction. Historically, the regulation of drainage has for the most part been left up to the public through civil actions in our Courts.

Some of those Acts which enable construction of drainage works include:

- The Rural and Urban Municipalities Acts;
- The Highways and Transportation Act and it's predecessor, The Public Works Act;
- The Private Ditches Act and The Drainage Districts Act, both repealed in 1981;
- The Conservation and Development Act, which enables a group of farmers to incorporate and construct works; and
- The Watershed Associations Act, which enables organizations and local governments to incorporate and construct works.

While it has always been recognized that drainage does cause some adverse effects downstream, those concerns were not addressed until 1976, following a few years of high runoff and precipitation. It was in that year that the Saskatchewan Government undertook a comprehensive study of drainage and related flooding.

The purpose of the study was to identify the specific problems associated with drainage and related flooding and recommend solutions through programs, legislation and administration.

A report and recommendations was submitted to the government in 1980 and resulted in the passage of The Drainage Control Act, proclaimed on January 1, 1981. That Act was placed under the administration of Saskatchewan Environment in the Water Rights Branch.

The Drainage Control Act was repealed on July 1, 1984, and incorporated nearly word for word, in the Province's Water Corporation Act, which places under one roof and one piece of legislation, the responsibility to plan, administer, regulate and develop the water resource under the mandate given to the Saskatchewan Water Corporation.

In broad terms, The Water Corporation Act prohibits the construction, extension, alteration or operation of any drainage works unless the written approval of the Corporation to do so has first been obtained. The Act applies to both surface and groundwater and to sewage works and water works. Passage of The Water Corporation Act has resulted in the repeal of several Acts, including the Drainage Control Act, The Water Rights Act, The Municipal Water Assistance Act, and others.

The Water Corporation Act states that the ownership and right of use of surface and groundwater is, and is deemed always to have been vested in the Crown.

"Drainage Works" are defined in The Water Corporation Act to mean any facility or other action constructed, done, operated or intended for the removal or lessening of surface water from land and includes the deepening, straightening, widening and diversion of the course of a stream, creek or other watercourse and the construction of dykes.

Some classes of drainage works are exempt under The Act and supporting

Regulations from requiring an approval. Some exemptions include:

- drainage works that were in existence on January 1, 1981, the date on which The Drainage Control Act was proclaimed;

- drainage works constructed under The Civil Defense Act, in case of disaster or emergency;

- drainage works located entirely within the boundaries of an urban municipality, where water is not diverted from the outlet through which the water would normally drain;

- drainage works where the works and water drained are both located entirely on an owner's land and the water drained does not drain from that owner's land; and

- certain drainage works associated with roads, where the works are constructed to accommodate existing flows.

The process for approval requires submission to one of our Regional Offices of an application, appropriate plan and report, a fee and written consent from appropriate municipalities where roads are affected. Other requirements may include consents from other affected land owners, advertising of the project in the local area and a report outlining the proposed future operation and maintenance of the project. Related engineering and technical services are provided at no cost by the Corporation to organizations which qualify for assistance under the Corporation's water policies and subject to availability of staff, by PFRA to individual farmers.

All proposals must be submitted to the Department of the Environment for prior approval. Also, drainage and flood control proposals involving provincial funding and Ducks Unlimited projects must be cleared through the Wetlands Committee, which is an inter-departmental committee established for the purpose of addressing and resolving agriculture - wildlife conflicts.

While the Act enables the Corporation to prosecute a person for constructing, extending, altering or operating drainage works without approval, the Corporation does not have a police force to keep the system honest. Instead, problem drainage works are dealt with through a complaint procedure provided in The Act.

Put simply, any person claiming to suffer, or anticipates that he will suffer damage, loss or injury caused by another person's drainage works may file a written complaint. The Corporation is required to investigate the complaint and render its decision within 18 months. The investigation usually involves interviews with all parties concerned, field investigations and surveys. If a solution cannot be worked out, a decision is rendered and an order can be made requiring the closure or alteration of, or changes or additions to the works complained against, or directing or discontinuing any operation, construction, extension, alteration, use or repair of the works complained against.

Appropriate powers are included in the Act enabling the Corporation to prosecute offenders and to enter upon any property for the purpose of carrying out work ordered, where an order has not been complied with.

The main thrust of the legislation is to enable drainage of surface water to be developed with some semblence of regulation and planning and with due regard to downstream effects. Also, it provides a mechanism for a person adversely affected by another person's drainage works to have his problem resolved without having to go through the Courts.

All decisions of the Corporation with respect to approval or denial of drainage applications, or terms and conditions attached to approvals and decisions and orders related to complaints are subject to appeal to the Water Appeal Board, appointed under The Water Appeal Board Act, which is administered by the Saskatchewan Department of the Environment. The Board is presently comprised of 4 farmers and an Engineering Professor from the University of Regina.

The appeal Board is similar to a court of Appeal. It's decisions are final except that any question of law may be appealed to the Courts. The cost to appeal is $100.

Guidelines Relating to Drainage Approvals

Guidelines used by the Corporation to determine whether or not drainage works should be approved for development and the terms and conditions to be attached to approvals are not as decisive as legislation.

As a result of extensive development of our land resource during the past couple of decades, problems have resulted on the main outlets of some of our river basins. By development, I refer to clearing, breaking, drainage, farming practices, road building, urban development and other activities, all of which change run-off characteristics. In some of our basins, nature has simply not been able to keep up with those developments and additional drainage is compounding the problems, resulting in flooding of farm lands and urban centres.

We attempt to approve drainage projects only where the outlet is considered to be sufficient to handle the extra flows. While we don't have a legal definition for "sufficient outlet", it is interpreted to mean that the drainage works would cause insignificant effects under certain flood frequencies. As a result of that approach, some applications for development of drainage works are denied pending actions to mitigate possible adverse effects that those works may cause. In some cases, works are able to be approved without restrictions on their operations. In other cases, works are approved subject to certain conditions relating to when and under what conditions the works can be operated.

Informal guidelines for approval of drainage works have been developed for 5 sensitive basins in Saskatchewan, briefly outlined as follows:

1. The Souris River Basin, located in south-east Saskatchewan, flows into North Dakota, through the City of Minot, then back into Manitoba, outletting in the Assiniboine River. Our guidelines for drainage development in the

Souris are consistent with recommendations made in the Souris River Basin Study. They state that drainage approvals should only be issued with conditions to control the flow until mitigative measures have been adopted to:

- flood proof the City of Weyburn; and
- re-locate flood prone farmsteads along a certain stretch of the river.

2. The Carrot River Basin, in the North East part of the province outlets in the Saskatchewan River near The Pas, Manitoba. Flooding along the Carrot River Valley has resulted in a freeze against major drainage projects which would have an effect on flood peaks, volumes or duration of flooding along certain stretches of the river until a solution to main stem flooding has been implemented.

3. The Qu'Appelle Basin, flows from Saskatchewan into Manitoba. In general, projects involving drainage upstream of Pasqua Lake will be reviewed in regards to local concerns and may be allowed to proceed only under specific flow conditions.

4. The Quill Lake Basin, is located in east-central Saskatchewan. Because it is a dead-end basin, all drainage projects which would increase the quantity of flow over estimated pre-drainage conditions into the Quill Lakes are placed in abeyance until a commitment has been made to resolve the flooding problems around the Lakes.

5. The Assiniboine River, located in east-central Saskatchewan experiences significant flooding, siltation, and erosion during and after a flood event.

In general, controlled drainage is allowed where the outflow can be regulated to the extent of the natural overflow. Also, drainage works are allowed in the Assiniboine basin where an additional quantity of water is not contributed and where it can be concluded that an increase in peak flows will be dampened to the flows which would have occurred without the drainage works before the main outlet is reached.

In addition to drainage approval guidelines for the 5 major basins which I have just mentioned, draft guidelines have been prepared for six smaller sub-basins which experience flooding problems. Needless to say, imposition of guidelines for approval of drainage works causes much controversy. Some suggest that the guidelines are too restrictive and others suggest that they don't go far enough.

That concludes my presentation. I realize that it has given you only an overview of legislation and development guidelines as they relate to agricultural drainage in Saskatchewan.

In summary, several Acts are in place in Saskatchewan which enable development of drainage works, but The Water Corporation Act provides a means to regulate and control those developments through an approval requirement. The Act also provides a mechanism for dealing with complaints against problem drainage works. All decisions, actions and orders of the Corporation are subject to appeal to the Water Appeal Board.

In certain basins which experience drainage and related flooding problems, guidelines are used as an aid for deciding whether or not approvals will be issued for drainage developments and the terms and conditions which are to be attached to those approvals.

In Saskatchewan, drainage and flooding is a thorny problem which we are trying to address through a planned and regulated approach and, hopefully, with future new and expanded programs.

It is recognized that if we hope to provide drainage and some degree of flood protection for prime agricultural lands, significant funds will have to be spent to off-set the effects through major channel improvements, land purchase and other programs.

HISTORY OF AGRICULTURAL LAND DRAINAGE AND DRAINAGE REGULATION IN NORTH DAKOTA

By: David A. Sprynczynatyk, P.E. 1/
Cary Backstrand, P.E. 2/

Drainage has been a part of North Dakota since before statehood. Without drainage, much of eastern North Dakota would not be what it is today: a thriving agricultural community. This paper will present a history of drainage in North Dakota from the early days of settlement to the present time. It will also address the overall need for drainage and the benefits derived from proper drainage. Finally, it will address the resulting regulation of drainage that has occurred within the state.

A look at the history of early North Dakota would tell us a great deal about agricultural land drainage. The Federal Government opened the Dakota Territory to homesteading in the year 1863. The first homestead in North Dakota was recorded in the Red River Valley in 1868. From then on, there was extensive settlement within the area. As the settlers moved into the area, they recognized that the lush Red River Valley had the potential for a prosperous agricultural community. But they were faced with one problem: the fact that the Red River Valley was very flat and that water did not always drain from the land.

The Red River Valley is not a true river valley in the sense that it is not well defined and not well drained. The Red River Valley is actually the bed of the prehistoric Lake Agassiz. In geological terms the Red River Valley is very young, only between 10,000 and 12,000 years old. Because of its geologic youthfulness, a well-defined natural

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1/ Director of Engineering, North Dakota State Water Commission

2/ Chief, Regulatory Section, Engineering Division, North Dakota State Water Commission drainage system has not developed, nor is it likely that it will.

It was recognized very early that the economy of the area would be dependent upon agriculture. It was also recognized that in order for the flat valley land to be developed, drainage systems would have to be an integral part. Thus records show that as settlers moved into the area, drainage systems were built to allow land to be farmed. By 1875, because of the drainage that had taken place and the resulting land improvements, large farms known as "Bonanza Farms" were able to operate in the Red River Valley.

As the Red River Valley was being settled and drained, other settlers came into the area and continued to move westward. These areas were also developed with an agricultural economy. In particular the area around Devils Lake, which is west of the Red River Valley, was developed. It, too, required extensive drainage. Another area further west was within the Souris River Basin. The area within the Souris River Basin was also a prehistoric lake bed, similar to the Red River Valley. Records show that prior to 1900, extensive drainage also took place here. This allowed for the successful development of farms.

The first drains were constructed by hand or by horse-drawn scrapers. In marshy areas where horses could not be used, a machine called a capstan ditch plow was used. A plow was pulled by two capstans, each of which was turned by a team of horses. Although drainage was difficult it was extensive, and records show that by the year 1900, over 72,000 acres of land had been included within established districts.

During the late 1800s and into the early 1900s, development continued and drainage took place at a rapid rate. A number of extreme climatological events, including floods, occurred during the late 1800s. As a result of the floods, the rate of drainage continued to increase. By 1920, over 1,240,000 acres of land were included within drainage districts. This drainage extended throughout much of the eastern third of North Dakota.

By the 1930s, much of the land had been drained. During the drought of the 1930s, drainage came to a standstill. In the thirties, the rains stopped and most of North Dakota became known as a dust bowl. Because of the inability to produce crops, tens of thousands of disillusioned people left the area. In 1936, only about a third of the wheat acreage in North Dakota was harvested because of massive crop failures. Drainage districts were no longer being created. In fact most of the existing drains, both natural and artifical, were filled with blow dirt. Many of these drains were eventually reopened, though some have yet to be reclaimed. Although drainage nearly halted, records show that by 1940, 1,380,000 acres were included within drainage districts, and that 940 miles of main drains were in place.

In the early 1940s the rains returned, and once again the need for proper drainage was evident. However, due to lack of capital during World War II, the establishment of new drainage districts and construction of large main drains was minimal. After the war years, construction of drains increased. Federal programs were available to help reclaim the land. A need to upgrade the highway transportation system, was evident, and many of the roadways in the state were improved. Modern earthmoving equipment was being used to move large quantities of earth. Well-designed highway ditches were constructed. With the highway ditches available for outlets, and federal money available for farmers to drain their land, indiscriminate drainage was becoming a serious problem.

During the 1950s, the Soil Conservation Service, a branch of the United States Department of Agriculture, was involved in planning and constructing a number of watershed projects which included drains, retention structures, and other conservation measures. Twelve of these watershed projects covering 1.5 million acres, have been completed in North Dakota. Although these projects included over 415 miles of drains and channel improvements, the projects also included 49 dams which have a storage capacity of over 100,000 acre-feet. Although well-planned and designed, these projects were constructed without state or local regulation.

By 1955, over 2,000,000 acres of land had been included in drainage districts in the State of North Dakota. From that point on, people were more aware of the potential impacts and consensus raised by drainage.

Today landowners continue to drain. It might be helpful to understand why they do so. The primary goal of agricultural drainage today, as it has always been, is increased crop productivity. As was the case 100 years ago, a properly designed drainage system will remove excess water from the surface and the subsurface of the land, thus enhancing productivity. It is understandable why a North Dakota farmer recently said, "If I can't drain, I can't afford to farm." It is not uncommon for a properly-designed drainage system to pay for itself in one to five years as a result of increased yields. A properly-designed drainage system will also increase land values.

Water lying on the surface of land is considered by many to be a nuisance. A proper drainage system provides a number of benefits to the farmer. There is a savings in operating expense and time since a farmer will not have to work around the wet areas. Although tile drains have not been used to a great extent in North Dakota, they have been used extensively in some parts of the country. In North Dakota, almost all drains have been open ditches on the surface. These open ditches may also help to control groundwater in the area, allowing better soil aeration and increased bacterial activity which will result in increased fertility and soil water holding capacity. Added dry soil depth can also mean stronger and deeper rooting systems, providing some protection during mild droughts. Drainage of small ponds reduces habitat attractive to blackbirds, which have been a major cause of depredation to crops like sunflowers.

From the very beginning as land was being reclaimed, drained, and put into agricultural production, the need to regulate drainage and to establish drainage districts became apparent. The first law dealing with drainage in the Dakota Territory was enacted in 1882, seven years before statehood. The 1882 Act enabled landowners to drain and reclaim land.

North Dakota became a state in 1889. In 1893, the State Legislature repealed the 1882 Law and passed extensive legislation providing for establishing, constructing, and maintaining drains. The Legislature provided for the establishment of boards of drain commissioners to implement the legislation. These boards were established in a number of counties. Their main objective was to reclaim the land by constructing drains throughout the counties.

The drainage law of 1893 stood for many years. In the early 1900s, it encouraged and provided for the convenient establishment of drainage systems. Where boards of drain commissioners were established, the law encouraged construction of drains without regard for downstream impacts. The 1893 Law did not regulate drainage in areas where boards of drainage commissioners were not established.

In 1957, after the public became more aware of drains and concerned about impacts, the North Dakota State Legislature enacted extensive drainage laws which basically remain the same today. The primary purpose of the 1957 Law was to require a drainage permit to construct a drain. That law simply stated that before anyone could drain a pond, slough, or lake which had a drainage area of 80 acres or more, a permit would have to be obtained from the local Water Resource Board and from the North Dakota State Engineer. Drains constructed by a state or federal agency were excepted from the permit requirement.

In 1975 the Legislature decided a major revision requiring permits was necessary to strengthen the drainage law. An individual who drained without a permit is now subject to criminal prosecution. Also in 1975 the Legislature placed the primary authority to close illegal drains with local water management entities. This has created some problems since local water managers are often farmers who drained their own land.

Since 1975 there has been a greater effort to enforce the drainage laws. In considering drainage permits, the state and the local unit of government must consider not only the downstream impacts of proposed drains, but also the public interest in natural resources as well.

In North Dakota local units of government generally are defined along political boundaries, and not along hydrologic boundaries. Since water and nature do not recognize the political boundaries, disputes over drainage arise between water management entities.

Over the years a number of Federal actions have influenced North Dakota's drainage law. In 1956, the United States Congress passed the Fish and Wildlife Coordination Act. This Act required agencies of the federal government involved in drainage projects to first consult with the United States Fish and Wildlife Service concerning conservation of wildlife resources. The intent of the Act was to prevent the loss of wildlife habitat resources, and to provide, where possible, the development and improvement of these wildlife resources.

The National Environmental Policy Act, passed in 1969, declared that it would be a national policy to encourage a productive and enjoyable harmony between man and his environment. The Act was to promote efforts which would prevent or eliminate damage to the environment, and to stimulate the health and welfare of man by enriching his understanding of the ecological systems and natural resources of the nation.

A 1977 Presidental Executive Order ordered federal agencies to take action to minimize the destruction and loss of wetlands, and to preserve and enchance the natural and beneficial values of wetlands.

During the early years wildlife was abundant throughout the Red River Valley. As the area was developed and put into agricultural production, the wildlife habitat was drastically reduced. In recent years there has been a great interest in preserving wildlife habitat, specifically wetlands, in order to increase wildlife populations. As a result, there is direct conflict between the agricultural and wildlife interests. This conflict has had a significant influence on the changes in the drainage laws in recent years.

Some states have enacted laws regarding the preservation of wetlands and wildlife habitat. North Dakota has not specifically done so, but the State Legislature has provided funds to the State Game and Fish Department to purchase easements. The Game and Fish Department may also acquire land to preserve wildlife habitat areas. The State Waterbank Program has been established, but to-date has not been funded. The Waterbank Program would provide for payments to landowners to preserve certain areas.

Recently, one of the local water management entities and the North Dakota Game and Fish Department signed an agreement of understanding to mitigate wildlife habitat areas that would be destroyed as a result of a drainage project. Although this has been done at the federal level, it is the first time that it has been done at the state and local level.

As a result of environmental awareness, the 1981 Legislative Assembly amended the law to require the review and consideration of other items of public interest, particularly environmental concerns. When an application to drain is received by the State Engineer he must make a determination as to whether or not the drainage is of statewide or interdistrict significance. This determination is based on a number of criteria which include:

1) whether the drainage would affect property owned by the state or a political subdivision;

2) whether sloughs, ponds, or lakes having recognized fish and wildlife values will be drained;

3) whether a meandered lake will be drained;

4) whether or not the drainage will have a substantial effect on another water management entity;

5) whether the project would convert previously non-contributing areas into permanently contributing areas;

6) whether an assessment area will be included in the project.

After these considerations are made by the State Engineer, the permit application is sent to the local water management entity. If the State Engineer declares the application of statewide or interdistrict significance, a local hearing is held. The local water management entity must review the application and consider a number of specific items in approving or disapproving the permit. These include:

1) whether the flow or quantity of water to be drained will overburden the watercourse into which the water will be drained;

2) whether the drainage will flood or adversely affect the lands of lower proprietors;

3) whether flowage easements are required;

4) whether it is shown that there will be a significant decrease in the water quality resulting from the proposed drainage project;

5) whether in evaluating the entire watershed, the resultant drainage will significantly increase flooding problems in the watershed;

6) whether the permanent storage of water on land in the application area is beneficial;

7) whether the area's erosion potential will be increased significantly due to the drainage of the water and the subsequent lack of wetlands to retard erosion;

8) whether type IV and V wetlands as determined by the State Engineer, exist in the application area, and if so, those wetlands shall not be drained unless overriding circumstances exist;

9) whether the agricultural productivity resulting from the drainage project will increase significantly;

10) whether the drainage project will decrease local flooding problems;

11) whether fish and wildlife values have been considered;

12) whether there are any other factors deemed important by the water resource district.

If the State Engineer had determined the drainage application is not of statewide or interdistrict significance, the decision of the local water management entity is final if not appealed to a court. Upon approval by the water management entity, this application to drain becomes a permit to drain.

If the drainage is of statewide or interdistrict significance, it will be necessary for the local water management entity to return the permit application to the State Engineer for final decision. The State Engineer will then make an independent review of the project and conduct a State Engineer's hearing. Approval by both the local water management entity and the State Engineer constitutes a permit to drain. Disapproval by either constitutes rejection of the application.

In conclusion, the history of drainage and drainage regulation in North Dakota has been long and interesting. In the early days drainage helped to develop the agricultural industry within the state. Over the years, the state has seen fit to increase its regulation of drainage. Although the regulations have not solved all of the problems often associated with drainage, they have helped to control drainage which continues to contribute to North Dakota's agricultural economy.

AG. LAND DRAINAGE - A VIEW FROM THE FIELD

W.R. (Bill) Poole, Manager
Turtle Mountain Conservation District, Deloraine, Manitoba

Since Manitoba's conservation districts represent a unique approach to soil and water management in Canada, I should perhaps - for the benefit of those of you from outside the province - preface my remarks with a brief outline of the way they are organized and administered.

In 1976, the provincial government combined two previously - existing pieces of legislation into the current Conservation Districts Act. Under that Act, a municipality or a group of municipalities may apply to the Minister of Natural Resources for the formation of a district "to provide for the conservation, control and prudent use of resources."

On the basis of that application, the province prepares a proposal which shows its recommendations for district and sub-district boundaries and the land assessment included within those boundaries. While the legislation suggests that the boundaries follow natural watersheds - and, in practice, that is normally done - there is no absolute requirement that a district be formed on that basis.

The proposal is then forwarded to the municipalities which would have land included in the district. The councils have 60 days to accept or reject the proposal. Assuming that the proposal is accepted, the district is established by order-in-council.

Once established, a district is governed by a local board. The municipal corporations appoint one council member and one ratepayer to a committee for each sub-district that has land in their municipality. The sub-district committees each elect a chairman and those individuals, along with one person appointed by the province, serve as the board for the district.

Under our current legislation, the boards may develop programs for:

"(a) drainage improvement, development and maintenance,

(b) flood control,

(c) soil conservation,

(d) water conservation,

(e) recreational development, or

(f) such other programs of resource conservation and development as the board may deem necessary or desireable."

The costs of the programs are shared by the province and the district. Depending on the type of program, the provincial share currently ranges between 70 and 90 percent, averaging out at approximately 75 percent of a district's total budget. In addition, the province provides the engineering and technical assistance required to develop and deliver many district programs.

The local share of the cost may be raised through municipal levy, direct charges to landowners or from grants, bequests and gifts. The order-in-council establishing a district authorizes them to request up to 10 mills - based on land assessment only - from the included municipalities.

At the present time, there are five conservation districts operating in Manitoba, covering approximately 15 percent of the agricultural area of the province. They range in size from about 370 square miles to just over 2700 square miles. While each of the districts offer a variety of programs, my discussion today will be limited to a brief consideration of some of the water management projects being undertaken.

Due to local differences in climate, topography and soil type, there is a wide range in the types of water management projects being developed within the districts. There is, however, one kind of work which is relatively common to most of them.

Many of the natural watercourses in the province have suffered erosion damage in some reaches and sedimentation in others. While a portion of that is a natural result of water obeying the law of gravity, the process has been accelerated by changes in land use and alterations to natural drainage patterns since the time of settlement. To solve some of the problems caused by the erosion and sedimentation that has occurred, most districts do what is commonly called runway stabilization work on natural watercourses.

Intended primarily to improve low-flow conditions, the work re-establishes a uniform gradient in the watercourses and reslopes the sides. The channel is then seeded to forage crops to protect it against future erosion. The type of work being done does not usually change high-flow capacities in the channel.

Under normal conditions, runway stabilization work begins at the downstream end of the channel and progresses upstream. In some instances - particularly on steeper slopes - the work will be started at the upstream end to minimize the potential for erosion damage prior to the forage crops becoming established.

Scattered over the province as they are, Manitoba's conservation districts also encounter a wide range of conditions that can't really be classed as "normal". Due to the runoff volumes, gradients and soil types involved, the districts along the Riding Mountain escarpment in particular have had to try some special techniques to attempt to solve unusual problems.

When you think of sedimentation, you normally think of problems associated with the transport of silt, sand and clay. In the Whitemud and Turtle River districts, problems with eroded shale can add a new dimension. The amount of shale carried down with runoff water is sometimes so large that drains can become completely blocked and may even, in severe cases, end up being above prairie level. While the shale must be cleaned out to re-establish capacity in the channels, simple clean-outs are obviously not the final solution to the problem. Headwater controls and shale traps are being investigated as preventative measures.

Gradients and/or soil types are such in some areas that normal grassed channels don't provide sufficient protection against erosion. In those cases, specialized construction methods such as wide channels or drop structures have been utilized to reduce erosion hazards. The drop structures may be concrete installations or simple rock "falls" depending on conditions.

Although not usually thought of as a season with drainage concerns, winter can present some special problems on watercourses in Manitoba. The Whitemud conservation district has suffered especially from the icing caused by winter-time flows from springs. Double culvert installations and drain-off slots in drop structures have greatly reduced the damage caused by pressures from icing in the structures.

Just as channel projects sometimes impact on wildlife, so too does wildlife have an impact on some drainage channels. Canada's national symbol, the beaver, presents some special problems on watersheds arising in the Riding Mountains. As they migrate downstream out of the national park, the animals often try to set up housekeeping in places where their presence isn't appreciated. Dams built in natural or constructed drainage channels can cause serious flooding of agricultural land.

Wildlife agencies, most notably Ducks Unlimited (Canada), have become involved in some water management projects with conservation districts. The Lonely Lake and Portia Complex projects in the Alonsa conservation district are the most extensive examples of such co-operation. In those projects, outlet channels and control structures provide more stable water levels; benefiting both agriculture and wildlife.

The majority of conservation districts, in addition to their work on natural watercourses, are also involved in the construction and maintenance of drains to service agricultural land. While they do not normally provide first order, on-field drainage, the districts do construct drainage channels which can serve as outlets for landowners.

Some districts have also undertaken runoff and flood control projects. In my own district, the board has tried two different types of structures in the past three years. In one, the design is such that water is only stored on a temporary basis. Runoff flows are released immediately through an uncontrolled 24 inch culvert. In the other - where a much larger storage capacity is available - the structure will serve a dual purpose. It will combine low-level permanent storage with additional capacity for runoff control.

Water storage projects are also a feature of some conservation district programs. In most cases the projects involve the construction of small dams, a fairly routine kind of work. One relatively new approach which has been tried in one district on an experimental basis involves pothole consolidation. In that project, an attempt was made to amalgamate the water from a number of small potholes - mainly on cultivated land - into one storage area. The project has helped the landowner rationalize his tillage patterns while still keeping the water on his own land and avoiding conflicts with downstream landowners. In this particular instance, the stored water has to be used up in small-scale irrigation on alfalfa in order to re-establish storage capacity for the following spring's runoff.

That's a very brief look at the water programs in Manitoba's conservation district. As you have seen, they cover much more than just drainage and, in my mind, that is as it should be.

With some notable possible exceptions - Manitoba's Red River valley and Interlake regions, parts of British Columbia and isolated, rather small areas scattered throughout the prairies - western Canada requires water management programs rather than drainage programs.

In spite of the fact that in some areas, in some years, we have seasonal excesses of water, the vast majority of western Canada is a moisture deficit area for agricultural crop production. By mid-July or early August, we have lost more moisture through evaporation and transpiration than we have received from precipitation. Given those conditions, it makes no sense to me to continue hurrying our seasonal water surpluses - which usually occur as a result of snowmelt - out of the agricultural parts of the prairies and off to Hudson's Bay. Somewhere between one-quarter and one-third of our average annual precipitation falls as snow. In the majority of the west, we cannot afford to continue giving much of that moisture away by either actively or passively over-emphasizing drainage.

While the provision of adequate drainage channels may well often be one component of a complete water management plan for the moisture-deficit portion of western Canada, in my opinion, it should never be considered to be the sole component. At the risk of belaboring it, let me repeat this point once more: in most of western Canada, we must adopt a complete management approach to water rather than looking for simple drainage solutions to seasonal surpluses.

Adopting that kind of approach will, of course, complicate the decisions which must be made. The solutions to drainage problems are relatively straightforward. Given adequate background information, one need only determine channel capacities, gradients, side slopes and the like; basically an exercise in applied mathematics.

In a complete water management equation, one must consider those same factors plus things like land management practices, impacts on wildlife, effects on groundwater levels, potentials for soil salinization and many more. As the other factors are added, the equation becomes increasingly more difficult to solve and, in fact, the degree of difficulty may appear to be so great that almost no-one will even attempt a solution.

To a large extent, I think that is what has happened with respect to the regulation of pothole drainage on farms in this province. There are so many aspects to that question - so many factors in the equation, if you will - that virtually nothing is being done to address the question.

If anything, that lack of action is compounded by the fact that both the provincial government and the municipalities, through two separate pieces of legislation, are granted some regulatory authority with respect to the drainage of water. As a result, each has maintained that the regulation of pothole drainage is the other's responsibility. I expect that everyone in this room is politically astute enough to realize what the outcome of that situation has been.

A few moments ago, I mentioned passive over-emphasis of drainage. By our collective inaction in not coming to grips with the difficult question of regulating pothole drainage, we have, albeit passively, encouraged that practice to continue. Manitoba has lost a tremendous number of prairie wetlands since the time of settlement, and I don't imagine the situation is much different in the other prairie provinces.

In my home area, the southwestern part of this province - which, incidentally, also happens to be the most arid region in Manitoba - Ian Milliken did a study on wetland loss for the provincial Department of Natural Resources a few years ago. He found that 3,320 wetlands had been destroyed in a 1,042 square kilometer block between 1971 and 1979. That works out to a loss of very nearly one wetland per section per year in that block.

I do not doubt that many of those wetlands are now more productive for having been drained. Just as surely, I also do not doubt that many of them, for any one or more of a variety of reasons, are less productive now than they were as undisturbed wetlands. The tragedy of the situaion is that we have lost the benefits those latter types of wetlands used to have - for flood storage, for groundwater recharge, for wildlife habitat, and for the beauty they added to our landscape - simply because we have not applied ourselves to solving the water management equation for prairie wetlands.

I do not have the solution to that complex equation; I'm not even sure of all the factors which should be included. I don't think that any other individual or group - not the engineers, nor the biologists, nor the farmers, nor the conservation district boards - has the solution either. I do think, however, that if we worked together, each adding our experience and expertise, we could solve that equation and many others for the benefit of all.

In the mid - 1940's, shortly before his death, Aldo Leopold wrote these words:

"Few people realize that the marvelous advances in technique made during recent decades are improvements in the pump, rather than in the well."

Those marvelous advances in technique of which Leopold spoke have continued and accelerated during the past 40 years. They remain, however, only improvements in the pump.

Our basic resources - the sun, air, soil and water-are still the well which sustains all life on this planet. In the final analysis, our primary responsibility should be - must be - to those resources.

I am personally convinced that groups like Manitoba's conservation districts - established on a watershed basis, governed by a locally-appointed board and receiving technical and financial support from senior levels of government - can play a significant role in formulating and delivering rational water management programs in Canada.

REFERENCES

Leopold, Aldo - "A Sand County Almanac" Ballantine Books

Milliken, Ian - 1980. "If deer are to survive - a habitat loss study in southwestern Manitoba 1971-1979." MS #80-33, Man. Dept. Nat. Res., Winnipeg

ENGINEERING AND EDUCATION FOR ON-FARM DRAINAGE IN MANITOBA

by

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ABSTRACT:

Manitoba Agriculture provides technical and extension services that improves field drainage on approximately 160 quarter sections (10,000 ha) annually. This is accomplished with limited staff resources (1 specialist, 2 summer students and the assistance of other Department staff as their time permits). High quality support by Regional staff and extension activities geared to practical on-farm results are important aspects in the delivery of the Farm Water Management Program.

The program currently emphasizes four activities:

1. Up-dating and Adapting Drainage Standards to Manitoba
2. Summer Student Surveying Service
3. Drainage Surveying Schools for Farmers
4. Water Management Investigations

ENGINEERING AND EDUCATION FOR ON-FARM DRAINAGE IN MANITOBA

INTRODUCTION

The variety of on-farm drainage problems in Manitoba can be summarized as:

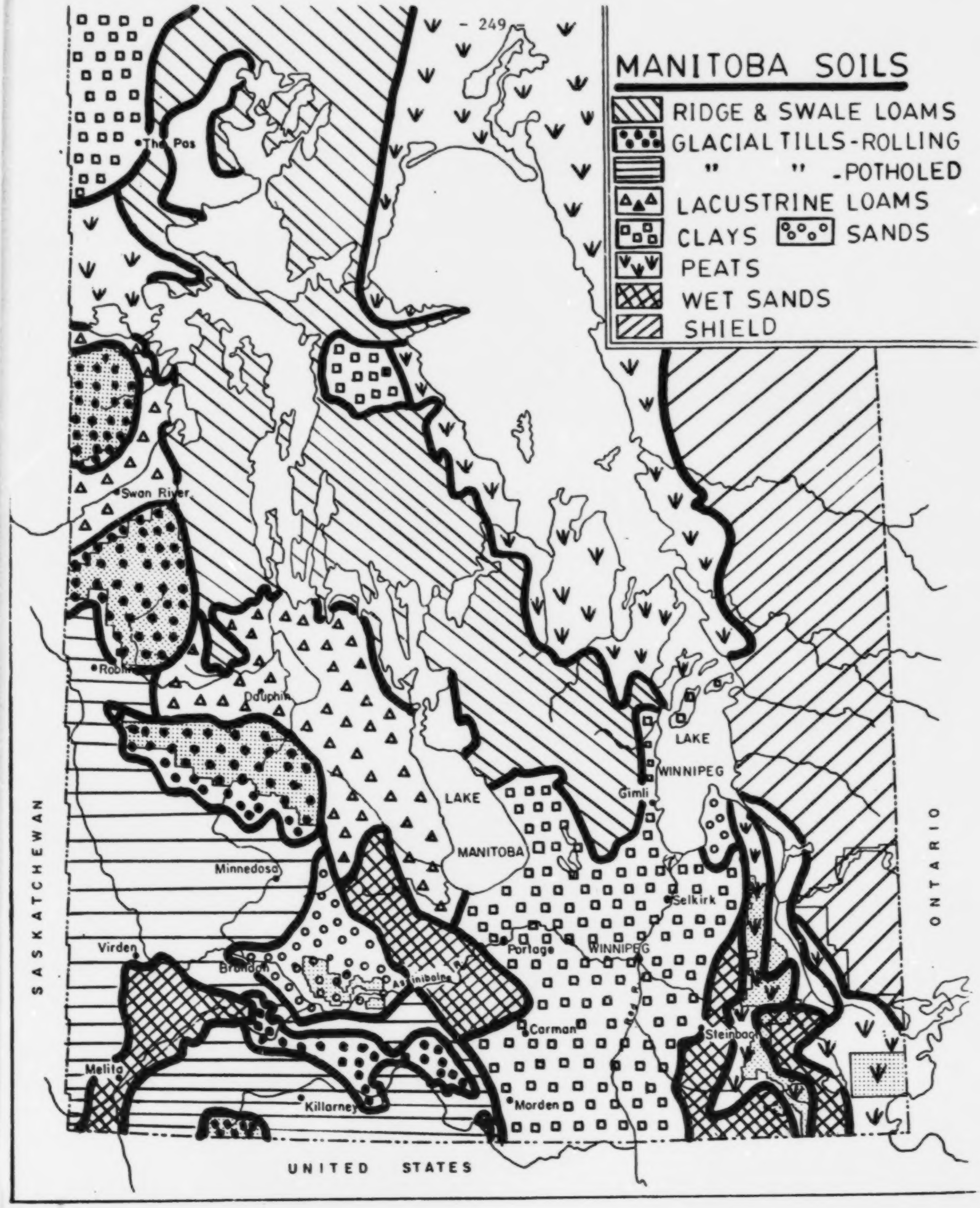
1. Surface drainage problems on 2.2 million hectares of flat, fine textured clay soils, particularly those in the Red River Plain.
2. Pothole drainage of spring snowmelt in the moisture deficit glacial till plains of Western Manitoba.
3. Fluctuating high water tables in 0.3 million hectares of Wet Sands. Alternately, waterlogging and drought stress can be experienced by crops as the water table fluctuates in and below the root zone through the growing season.
4. Snowmelt surface water and water table management problems on 5 million hectares of organic (peat) soils in the fringe agricultural zone of Manitoba (0.6 million hectares are considered arable for crop production).
5. Salinity problems on 0.3 million hectares.

The most severe agricultural drainage problem in Manitoba has been and continues to be the removal of excess summer precipitation from the flat, lacustrine clays. The other problems identified have become more prominent issues in the last ten years as higher land prices have forced intensification of Prairie agriculture.

In the past, Manitoba Agriculture's service to on-farm drainage was confined to:

(a) a summer student surveying service (operating province-wide for at least the last 16 years) to assist farmers in upgrading their field ditches

(b) specialist advice on demand from Regional and Central staff agricultural engineers and soil management specialists.


MANITOBA SOILS
RIDGE & SWALE LOAMS
GLACIAL TILLS - ROLLING
" " - POTHOLED
LACUSTRINE LOAMS
CLAYS
SANDS
PEATS
WET SANDS
SHIELD
The Pas
Swan River
Roblin
Dauphin
LAKE MANITOBA
LAKE WINNIPEG
Gimli
Minnedosa
Virden
Brandon
Assiniboine R.
Portage
WINNIPEG
Selkirk
Red R.
Carman
Steinbach
Melita
Killarney
Morden
SASKATCHEWAN
ONTARIO
UNITED STATES

Issues like tile drainage in Manitoba, water conservation versus pothole drainage and crop failures due to field flooding in the Interlake Region justified the hiring of a Farm Water Management Enginner in 1980. The technical and extension service for Farm Water Management currently is being delivered through four activities:

1. Updating of Field Drainage Standards
2. Summer Student Surveying Service
3. Drainage Survey Schools
4. Water Management Investigations

Even with limited staff resources (1 specialist, 2 summer students and the assistance of other Department staff as their time permits), Manitoba Agriculture has been able to assist a significant number of farmers in upgrading their field drainage on the lacustrine clays while beginning to address the other water management issues in Agro-Manitoba. The Department has supplemented its traditional technical service with a practical drainage course that is beginning to show significant benefits.

FARM WATER MANAGEMENT PROGRAM

1. Field Drainage Standards

The success of any education program depends on the appropriateness of the material being delivered. Surface drainage to the major farm drainage concern in Manitoba. The first step in our extension program, then, was a review of field surface drainage standards. The American Society of Agricultural Engineers Standard, EP 302.2, "Design and Construction of Surface Drainage Systems on Farms in Humid Areas", plus field experience and the general availability of farm scrapers and blades for Manitoba farmers were all factors in the standards eventually adopted. Updating these standard was of immediate benefit to our surveying service. These standards are now generally used for the drainage schools, news releases, home study courses and will be released in Factsheets shortly.

Subsurface drainage standards have not been developed for Manitoba conditions because research on potential applications in different soil types (Wet Sands for example) is incomplete or lacking. Information from Alberta, Saskatchewan and the eastern provinces has been adapted when necessary on a site-by-site basis.

Water Management has been a priority for standard development and is discussed later.

The importance of practical and appropriate standards cannot be underemphasized. Manitoba Agriculture's experience is that a great deal of practical refinement takes place by working directly with individual farmers on their problems and installations.

TABLE 1

Field Surface Drainage Standards

Individual Random or Parallel System Ditch

DITCH GRADE				DITCH DEPTH				MINIMUM SIDE SLOPES
Maximum	**Ideal**	**Minimum**	**Minimum on very flat land**	**Maximum (m)**	**(ft)**	**Minimum (m)**	**ft)**	
0.3 m/100 m grass bottom and sides	0.2 m/100 m	0.1 m/100 m	0.05 m/100 m	0.8	2.8	0.15	0.5	10%

Spacings for Ditch Systems

	NO. OF DITCHES PER QUARTER SECTION	SPACING m	ft.
a) Random System	5	Will be determined by field's topography	
b) Parallel System	6	120	400
c) Parallel System with Land Grading or shallow laterals	4	200	640

2. Summer Student Surveying Service

The primary function of this service is to provide surveying, soils investigations and drainage/water management plans for farmers with out-of-the-ordinary excess water problems.

The surveyor (usually an agricultural engineering student) is responsible for:

(a) examining the proposed drainage or water management scheme with the farmer

(b) doing any soils investigations that are required

(c) conducting the survey with the farmer acting as the rodman

(d) drawing up plans showing the necessary ditch cuts for the field ditches and preparing recommendations for controlled drainage, or reservoir development for water management in appropriate situations.

The service is limited to 2 students to cover Manitoba and is supervised by the Farm Water Management Engineer and/or by a Regional Agricultural Engineer. Because of manpower restrictions, little publicity is given to the service but word-of-mouth advertising has resulted in a full workload for the last 3 years.

With the updated drainage standards and the experience accumulated from water management investigations, the summer student surveying service has been extended to soils investigations and water conservation designs when appropriate situations arise.

In-spite of limited manpower, the surveying service is very useful in providing specialized service for difficult drainage problems. In particular, drainage disputes between neighbours that normally would go to the extremes of civil suits have been resolved if both parties are willing to use the service as an independent agency to assess and provide solutions to the problem.

In addition, the immediacy of drainage problems the service has to handle each year forces staff to deal innovatively and practically with current land and water issues.

TABLE 2

Number of Quarter Sections Surveyed (1975 - 1984)

Region	1982	1983*	1984	Ten Year Total (1975 - 1984)
Eastern (east of Red River)	6	15	6	148
Interlake (north of Winnipeg)	13	37	11	139
Central (west half of Red River Valley)	14	5	10	183
Southwest (south of Riding Mountain)	12	22	12	156
Northwest (north of Riding Mountain)	7	5	15	116
TOTALS	52	94	54	742

* In 1983, in addition to the regular 2 students, a third student worked half-time in the Eastern Region.

Demand for surveys in pothole country (the Southwest Region) has been steadily rising over the last ten years even though the surveying service has not been given any publicity at all in that area. Since 1982, applications from the Southwest Region have gone through a careful screening process to ensure that agriculturally productive land is being developed by the proposed scheme. The demand for surveys has also pressured the Department into investigating and developing criteria for water conservation projects. Water conservation opportunities such as controlled drainage, backflood irrigation, pothole consolidation, (reservoir development) are incorporated into the plans returned to the farmer whenever possible.

TABLE 3

Advantages, Disadvantages of the Summer Student Surveying Service

Advantages	Disadvantages
1. Specialized low-cost service for difficult drainage problems.	1. Summer service only.
2. Support for Special Projects.	2. Limited number of students results in limited service.
3. Drainage/Irrigation training for students.	3. Extensive travel costs.
4. Minimal supervision.	

3. Water Management Investigations

The on-going questions of off-farm drainage of snowmelt in potholes in moisture deficit South Western Manitoba, water management in peat soils and more intensive production on Wet Sands have been tackled with specific projects that are useful in investigating proper design criteria and demonstrating alternatives to existing practices.

(a) Pothole Consolidation - Manitoba Agriculture and the Turtle Mountain Conservation District are involved in a pilot project on a quarter section near Boissevain, Manitoba. Pothole consolidation involves drainage of depressions and temporary potholes down to a reservoir (slough or excavated storage) in a self-contained watershed. Drainage is by surface ditches in the Boissevain project although subsurface drainage is another alternative. Construction on the project was started in the fall of 1982 and completed in the fall of 1983, although the reservoir is still undersized. Estimating run-off and sizing reservoirs is critical to the operation and economics of these projects. With immediate interest from other S.W. Manitoban farmers in applying the concept to their land, the Department responded by developing preliminary agronomic and engineering criteria for pothole consolidation. This was reported in a paper to the Agriculture Institute of Canada conference in August, 1984.

The project has been criticized for not providing habitat for wildlife. Since potholes and sloughs are important for waterfowl on the prairies, the concern is recognized and discussions are on-going on how this criteria can be modified to incorporate habitat for wildlife.

Although, the land use activities of agriculture and wildlife have traditionally been represented as mutually incompatible, in this case they are not necessarily so. Both Agriculture and wildlife specialists are interested in water conservation; the question appears to be in the mechanics of water management in these projects.

Irregardless, the debate over pothole consolidation should not overshadow what is the predominant practice by farmers in the glacial till plains. Farmers are upgrading land and production by off-farm drainage of potholes.

They are adopting this practice because ditching off the farm is the simplest solution, perhaps the only solution they are aware of, and alternatives that meet the farmers' needs and incorporate water conservation have not been developed or publicized. Because Manitoba Agriculture's summer student surveying service is open to all Manitoba farmers, the department has had to deal at a practical level with the issue of pothole drainage. Pothole Consolidation is one alternative being investigated.

(b) Water Management in Peats - One of the issues in development of peatlands for agriculture is providing drainage for peats while avoiding over drainage. About 25 ha of a 50 ha bog has been developed near Richer, Manitoba for raspberry production. A series of open ditches at 60 m spacings provide water table control in conjunction with a pump station. The bog is isolated from the outlet drains so field water tables can be controlled in isolation of water levels in the outlet drain. The system was installed in the fall of 1982, extended in the fall of 1983, and will eventually result in full development of the bog. Initial plantings of raspberry canes in the summer of 1983 established well and water table control has promoted optimum development.

(c) Wet Sands, Lagoon Seepage - A subsurface (tile) relief system was installed in the spring of 1983 on three sides of the MacGregor Lagoon to control high water tables in the adjacent farmland. The system of two lines of perforated tubing at depths of 0.5 m to 1.5 m and at spacings of 10 and 25 m from the lagoon's dikes successfully controlled water tables on the east and north sides of the lagoon while permitting the crop to subirrigate from the water table later on in the growing season. The west side of the system had a spring freezing problem in 1984 that prevented timely drainage of snowmelt. A third line with a Jensen surface inlet was installed on the west side of the lagoon in the fall of 1984 to correct this problem.

This project has highlighted water table control at optimum depths in Wet Sands, freezing problems in subsurface drainage systems and will assist in evaluating the use of surface inlets for surface drainage through subsurface systems.

4. Drainage Surveying Schools

Training farmers to do their own survey work and ditch designs is not a new idea in Manitoba. Regional Agricultural Engineers (Bob Rae and Doug Jackson) taught drainage schools in the Red River Valley in the mid '60's and mid '70's. Wally Happychuk, Agricultural Representative, revitalized the concept and in 1982, a manual to be used in a three day course was developed.

There has been a steady increase in demand for the course since the first four schools were run in the autumn of 1982. September and October are prime months for the schools since traditionally this is the time Manitoba farmers do maintenance work on their field ditches as part of fall tillage.

As figure 2 shows, schools are serving a specific area and drainage problem in Manitoba.

Schools are geared to upgrading field surface drainage on the flat lacustrine clays that are predominantly under cereal or special crop production. Schools are targeted for areas that are served by a network of municipal and provincial major drains.

Course content covers:

(a) resources for planning drainage surveys (air photos, soils maps)

(b) legalities of drainage

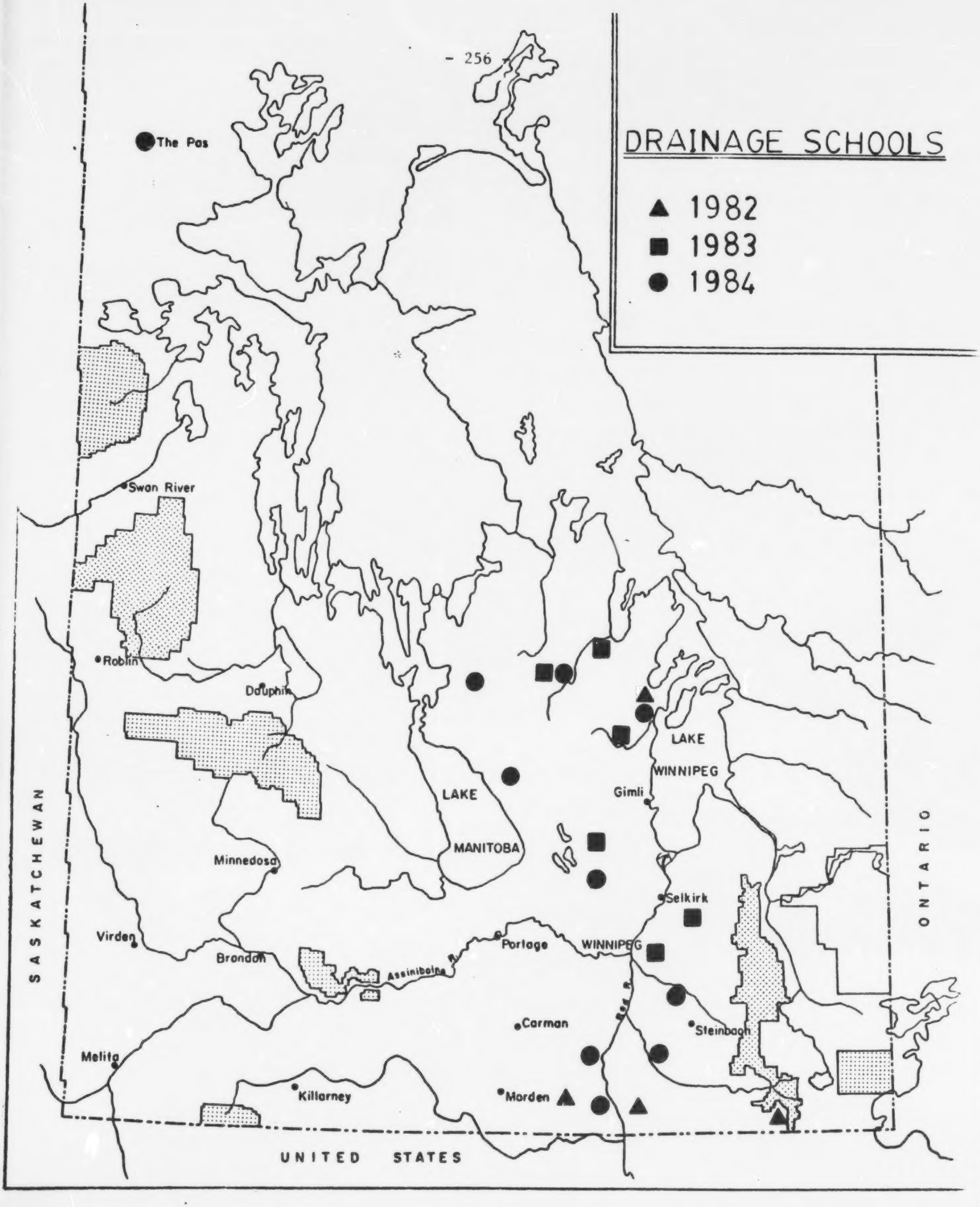
(c) theory of profile levelling

(d) operation of an engineer's level

(e) design of field ditches (profile plan for calculating ditch cuts).

(f) construction practices.

Essential to the course is the use of a representative field in the area for surveying practice by the participants. If weather conditions and other factors permit, the school finishes with construction of the ditches surveyed and designed by the participants. This has happened in 50% of the schools run to date.


DRAINAGE SCHOOLS
▲ 1982
■ 1983
● 1984
The Pas
Swan River
Roblin
Dauphin
LAKE MANITOBA
LAKE WINNIPEG
Gimli
Minnedosa
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SASKATCHEWAN
ONTARIO
UNITED STATES

TABLE 4

Drainage School Schedule

Day 1	A.M.	- Planning Surveys, Theory of Profile Levelling - Classroon
	P.M.	- Testing the Level, (Peg Test) - Field Start Surveying Field
Day 2	A.M.	- Continue Field Surveying - Field
	P.M.	- Ditch Design - Classroom
Day 3	A.M.	- Construction Practices, Quiz - Classroom
	P.M.	- Ditch Construction - Field

The emphasis is on practical, hands-on experience with the surveying instruments, learning a simple method for calculating ditch cuts in a real life situation. Because air photos are used as base maps for the surveying, metric is used throughout the course with translation to Imperial units as needed for understanding. Instruments for the schools are loaned from local surveying equipment dealers.

It is the farmer's option to buy his own surveying equipment. In general, the department attempts to supply surveying equipment to the Agricultural Representative's office after the course to loan out to participants who pass the quiz. Certificates are also sent to those who pass.

TABLE 5

Impact of Drainage Schools*

	Participants In		
	1982	1983	1984
No. of Schools	4	6	10
No. of Participants	40	63	82
Percentage of Participants;			
a) Who Have Done Surveying After Course		70%	30%
b) Who Have Improved Ditches After Course		85%	53%

	1982	1983	1984
c) Who Have Done Surveying and/or Ditching for Neighbours		23%	20%
Projected Number of Quarter Sections Improved (Cumulative)		164	30
No. of Quarters Improved - by Active Participant Annually		2.8	0.7
Satisfaction Level - Percentage Rating Course Good to Very Good		90%	86%

* Based on telephone survey of 20% of 1983 and 1984 participants, November 1984.

The fall of 1983 allowed ditch construction well into November. 1984 has been a poor year for this activity, consequently survey and ditching by 1983 and 1984 participants was significantly lower in 1984. However, the effect of drainage schools is cumulative, as participants from previous schools continue to survey and improve their drainage year by year. For example, for 1985, with no new schools and poor fall weather, a minimum level of activity (like 1984) would project into 50 quarter sections improved in 1985 by 1983 and 1984 participants. Or an open fall could result in over 300 quarter sections improved.

The cost-effectiveness of drainage survey schools as a departmental extension effort can be illustrated by the following comparison.

For the cost of a drainage school, the department can get 7 quarter sections surveyed by the summer student service. So if the farmers go out and improve only seven quarter sections the department has made the same investment in assisting in the upgrading of those quarters as it would if a summer student had done the work. Schools have averaged between 8 to 10 participants and the likelihood is that each farmer will be upgrading the drainage on more than one quarter section.

The other point in favour of the short course in the timeliness and scale of having effectively 185 surveyors out in the country handling their own drainage problems and their neighbours. And they've been trained to do it correctly and responsibly.

CONCLUSION

Although the summer student surveying service is limited, it provides some excellent benefits outside of its direct service aspects. For Agriculture staff, it provides on-going contact with current land and water issues. It benefits the development of drainage standards through daily application in what amounts to a rigorous testing of their suitability and practicality. Water management investigations are in response to real life problems. That also imposes time constraints. The department has not had the luxury of waiting for ideal solutions to come along or be developed for some of these problems. However, imperfect solutions do not satisfy farmers so there is always pressure to improve on ideas and design criteria.

The limitations on direct service through summer students has forced the department to go to extension education to have a larger impact in assisting farmers with their drainage problems. Manitoba Agriculture's experience is that the short course concept is cost-effective and can significantly influence farmers' activities. The short course concept also has potential for dealing with other farm water management issues. It has a high acceptance rate with farmers because it is applied, geared to a practical step-by-step solution to a real life problem.

References

1. "Design and Construction of Surface Drainage Systems on Farms in Humid Areas", (1983), ASAE EP 302.2, Agricultural Engineers Yearbook of Standards, American Society of Agricultural Engineers p. 446-453.

2. MacAlpine, N., Shaw, G. "Preliminary Selection and Design Criteria for Pothole Consolidation", (1984), Presented at Canadian Society of Agricultural Engineering Summer Meeting, Winnipeg Paper No. 84-303.

3. Singh, R.H., Howden, J.S. Somer, G.T., Pitura, F., Rigaux, L.R., "Does Farm Drainage Pay", (1973), Manitoba Department of Agriculture, Publication No. 538.

4. Slevinsky, L., Schellenberg, H., "Estimation of Potential Agricultural Drainage Benefits in the Marsh River Watershed", (1980), Unpublished Paper, Manitoba Department of Agriculture.

THE ECONOMICS OF DRAINAGE IN ALBERTA

Ronald Desjardins
Kathleen MacDonald
and
Darren Wutzke

October 1984

Production and
Resource Economics Branch
Alberta Agriculture

TABLE OF CONTENTS

1. Introduction
    - 1.1 Objectives
    - 1.2 Procedure

2. Review of Literature
    - 2.1 Increased Yields with Decreased Salinity
    - 2.2 Improved Field Efficiency
    - 2.3 Costs of On-Farm Drainage

3. The Model
    - 3.1 The Data
    - 3.2 The Value of Time Lost
    - 3.3 Yields
    - 3.4 Yearly Costs and Benefits
    - 3.5 Net Present Value

4. Analysis: Procedure and Results
    - 4.1 Procedure
    - 4.2 Results
    - 4.3 Sensitivity Analysis

5. Qualitative Costs and Benefits
    - 5.1 Benefits
    - 5.2 Costs

6. Summary and Conclusions

Appendix I

Bibliography

THE ECONOMICS OF DRAINAGE IN ALBERTA

R. DESJARDINS[1]; K. MACDONALD[2]; and D. WUTZKE[3];

1. INTRODUCTION

The Extent of the Drainage Problem

Approximately 25% of the land in central Alberta (64 ha/section) is affected by wetlands, including streams and rivers, as estimated by Rapp, Apedaile and Desjardins (1983). Sloughs and wetlands cover 44ha/section or 17% of the land within areas mapped as CLI Class 3 or better in the region north east of Red Deer. These wetlands are considered to be reclaimable.

This is a significant amount of land with perhaps some potential for drainage. It is however important to distinguish between true problem areas and areas not affected for a critical length of time. One way of identifying a problem area is where water is standing in a field longer than 2 days after a 3 inch rain (Singh et. al. 1973). This is a guide to follow, because crop damage occurs as quickly as 48 hours after being flooded. A crop can be completely destroyed within 6 days because of excess moisture. In terms of relative importance, drainage ranked high as a limiting factor to production, as shown in a recent survey of farmers in areas north of Red Deer.

> "Water is the most important limitation to land already in agricultural areas. This is shown by the fact that 96% of all farmers surveyed face such a problem and that surveyed water areas covered more than twice the area of the second limitation (water 2,037 acres; rockiness 782 acres)."
>
> Desjardins 1983 (1).

---

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[2] Section Head, Resource Section, Production and Resource Economics Branch, ADA.

[3] Research Assistant, Production and Resource Economics Branch, ADA.

Excess water creates major problems for agricultural producers. This problem has two aspects, in that it produces substantial losses of otherwise productive land and it decreases the efficiency of field operations. This latter effect was examined to estimate the additional cost of production caused by the presence of obstacles in a field.

> "For the four crops studied, there is a drop in efficiency from 100% in the no obstacle situation, to a range of 96.2% to 99.4% with obstacles present. The lowest loss of efficiency occurs with a permanent or semi permanent crop (e.g. pasture or hay crops)".
>
> Desjardins 1983 (2).

Apart from the problem of standing water there is the associated problem of salinity. Saline seeps reduce yields on an estimated 200,000 hectares of dryland and 80,000 to 120,000 hectares of irrigated land in Alberta (Vander Pluym, Paterson and Holm, 1981). The general cause of salinity and water-logging is an increase in the movement and build up of groundwater.

Drainage problems can be caused by local water and/or runoff. Local water is rainfall which falls on the problem area, and runoff is rain which falls in other areas of the field but flows to a concentrated area. Local water problems can be solved by improved drainage. Areas which have runoff water can also be greatly improved through drainage to speed up the removal of that excess water from the land.

Potential Benefits of Drainage

In order to determine if a drainage project is feasible, the associated costs and the expected benefits must first be compared. Two types of benefits must be considered: (1) quantitative or monetary benefits; and (2) qualitative or secondary benefits.

The major benefits which can be achieved from drainage are:

(i) Land use change - woods cleared, pasture broken up;

(ii) More intensive uses - improved yields, better rotations;

(iii) Reduced production costs - improved efficiency, reduced lost time due to machinery turning around or becoming stuck in wet spots; and

(iv) Improved resource allocation - shift crops between areas, change type of farming.

All of these benefits bring returns in the form of monetary gains. There are two types of costs which are associated with drainage: (1) physical costs (monetary costs); and (2) secondary costs of a project.

One thing to remember about a project is that costs are often underestimated and benefits overestimated. When this happens the payback period is extended. That is why each drainage project should be evaluated economically before being undertaken.

In this paper the major quantitative benefits will be examined. The model takes into account four major economic items. Because of the difficulties in evaluating some of the secondary benefits these will only be explained in qualitative terms. The secondary costs will be treated in the same manner. Due to the many different sizes and locations of sloughs and wetland, costs can only be estimated from other projects which have been undertaken in the province.

Sometimes farmers drain sloughs for reasons other than to increase the amount of productive farmland. They often do not take into account the physical costs. For example, one farmer drained six acres at a cost of $4,000 or $667 an acre. The biggest benefit was the extra efficiency gained, the farmer estimated that the extra six acres could be cropped with the variable inputs saved through the gain in efficiency. The gains in efficiency are sometimes more important than gains in yields. The final decision to drain the slough still rests with the individual farmer.

1.1 Objectives

In view of the extent of the excess water and salinity problems and the limited amount of current and relevant data on the economics of drainage and reclamation, a study was undertaken to analyze the economic feasibility of surface and subsurface drainage as measures for treating both problems. The main objectives of the study were:

(i) To develop a relatively simple computer model which could be used to determine the economic feasibility of a drainage project; and

(ii) To determine the conditions under which drainage would be economically feasible.

1.2 Procedure

The preparation of this paper involved five major components, these are:

(i) A review of the relevant literature;

(ii) The preparation of an appropriate model to measure the benefits arising from drainage;

(iii) The evaluation of various situations through the model, and an analysis of the results;

(iv) Discussion of the non-quantifiable costs and benefits; and

(v) Conclusions.

2. REVIEW OF LITERATURE

The model developed for this paper includes three major components derived from studies previously undertaken by members of the Production and Resource Economics Branch. This section reviews these papers, and provides a summary of their methodology and results. The methodology was then adapted to the needs of this paper.

The three components are:

(i) The benefit of increased yields which result from drainage of previously wet areas. This section considers two major wet area conditions, firstly, irrigated lands affected by a high salinity problem (based on the model used by Birch 1983, and later updated by Stochinsky,1984); and secondly, the case where only an excess moisture problem exists;

(ii) Benefits which result from a gain in field efficiency and thus a decrease in production costs. This was estimated through a model developed by Desjardins, (1983); and

(iii) The cost of drainage installation. Both surface and subsurface drainage options were considered. This portion was based on the design and installation costs reported by Rousseau (1983).

2.1 Increased Yields with Decreased Salinity

> "The major benefit from the drainage and reclamation of irrigated saline soils is the increase in crop yields".
> Stochinsky, 1984.

To derive the increased yield benefit two steps were identified:

(i) The estimation of the change in salinity level (Ec) or reclamation rate associated with drainage; and

(ii) The estimation of the yield increase possible with changes in the Ec level.

2.1.1 Reclamation Rate

> "The reclamation rate for saline soil is closely related to the type of soil, the level of salinity before drainage, the drainage design and the post-installation crop and soil management. Since it was impossible to take the effect of each of these factors into account in determining an "average" reclamation rate, the procedure used here was to define three reclamation curves based on published reports which may be representative."
>
> Stochinsky 1984.

A regression was established by plotting data obtained by Van Schaik and Milne (1962), on the drainage of shallow Chin loam soil near Vauxhall, Alberta, (see Figure 1). This regression has the form:

$$\ln (\text{Final Ec}) = \ln (\text{initial Ec}) - (b) (\text{water applied}).$$

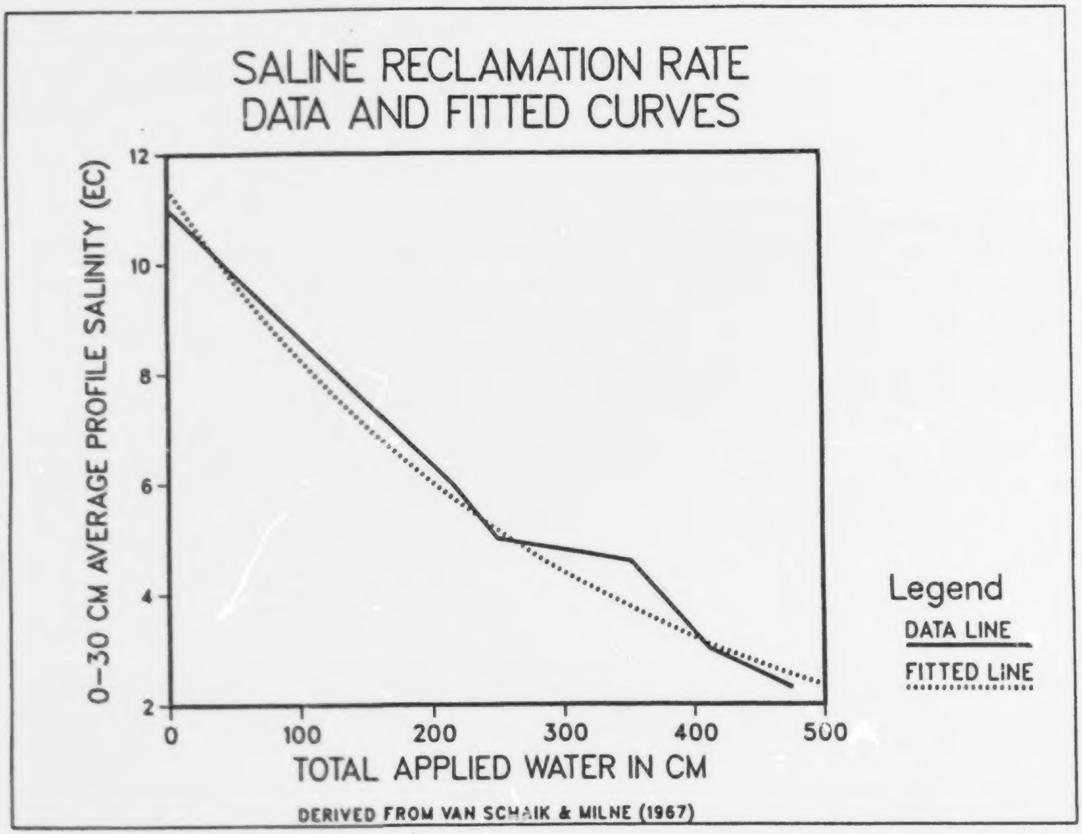
When tested with an application rate of 30 inches (76cm) this equation was found to have a b of 0.00317 Ec/cm, with a correlation coefficient of 0.959. Though the data base is small it was the best estimate of the yearly salinity level which could be obtained. This equation permits the estimation of the salinity level at the end of a water application period. For the purposes of this paper yearly estimates of the salinity level were obtained using the regression equation above.

2.1.2 Crop Response to Ec Level

For the purpose of determining the yield level, a linear model was developed.

The following extracts from Stochinsky (1984) are provided to better explain the high variety of factors affecting yields and the process used to derive crop response to Ec level. The analysis relates to wheat, barley and alfalfa.

FIGURE 1



SALINE RECLAMATION RATE DATA AND FITTED CURVES

DERIVED FROM VAN SCHAIK & MILNE (1967)

$$Yi = Yo - Yo (Eci - Ect) b$$

Yi = Yield in year i
Yo = Optimum Yield
Eci = Effective for year i Ec level
Ect = Threshold Ec level
b = Yield response factor
(% change yield per unit change in Ec.)

"Wheat is less tolerant of salinity during germination. The Riverside data (no saline water during germination) shows salinity having an effect above a threshold of 6.0 mS/cm, after which yield decreases 7.1% for each unit increase in salinity. Fowler and Hamm (1983) report that wheat yields decrease 11.1% for each unit increase in conductivity above 3.7 mS/cm. Holm (1983) calculates yields decreasing 7.7% for each unit increase in conductivity, no threshold limit was given. In this study, 3.7 mS/cm was adopted for the threshold above which salinity has an effect and 7.5% was assumed to be the decrease in yield per unit increase in conductivity.

Riverside data for barley shows a 5% decrease in yields for each unit increase in conductivity above 8.0 mS/cm. McKenzie et al. (1983) report an 8.8% decrease in yield per unit increase in conductivity above 2.1 mS/cm. Fowler and Hamm (1983) report a 6.7% decrease above 2.8 mS/cm. Bole and Wells (1978) report a decrease of 4.8% and Holm (1983) reports a decrease of 5.1% per unit increase in electrical conductivity. As with wheat, the Riverside data do not account for the sensitive germination stage. However, the other data, except for Bole and Wells, do not account for the lower surface salinity due to the leaching process. In this study, a decrease of 6% per unit increase above 5 mS/cm was assumed.

Alfalfa's yield decreases 7.3% per mS/cm increase above 2.0 mS/cm, according to Riverside data. Holm (1983) gives a 4.1% decrease in yield per unit increase in conductivity above zero. Holm's values may differ because alfalfa roots go deeper where saline levels are lower than where Holm's salinity levels are measured. If this is the case, irrigation water would provide the same benefits as deeper roots. Thus a 5% decrease in yield of alfalfa will be assumed for each mS/cm increase in conductivity above a threshold of 2.0% mS/c.".

Stochinsky (1984)

From these conclusions the three following equations were produced:

Wheat

$Yiw = Yow - Yow\ (Eci - 3.7)\ 0.077$

Barley

$Yib = Yob - Yob\ (Eci - 5)\ 0.06$

Alfalfa

$Yia = Yia - Yoa\ (Eci - 2)\ 0.05$

A response curve was obtained by plotting these equations (see Figure 2).

2.2 Improved Field Efficiency

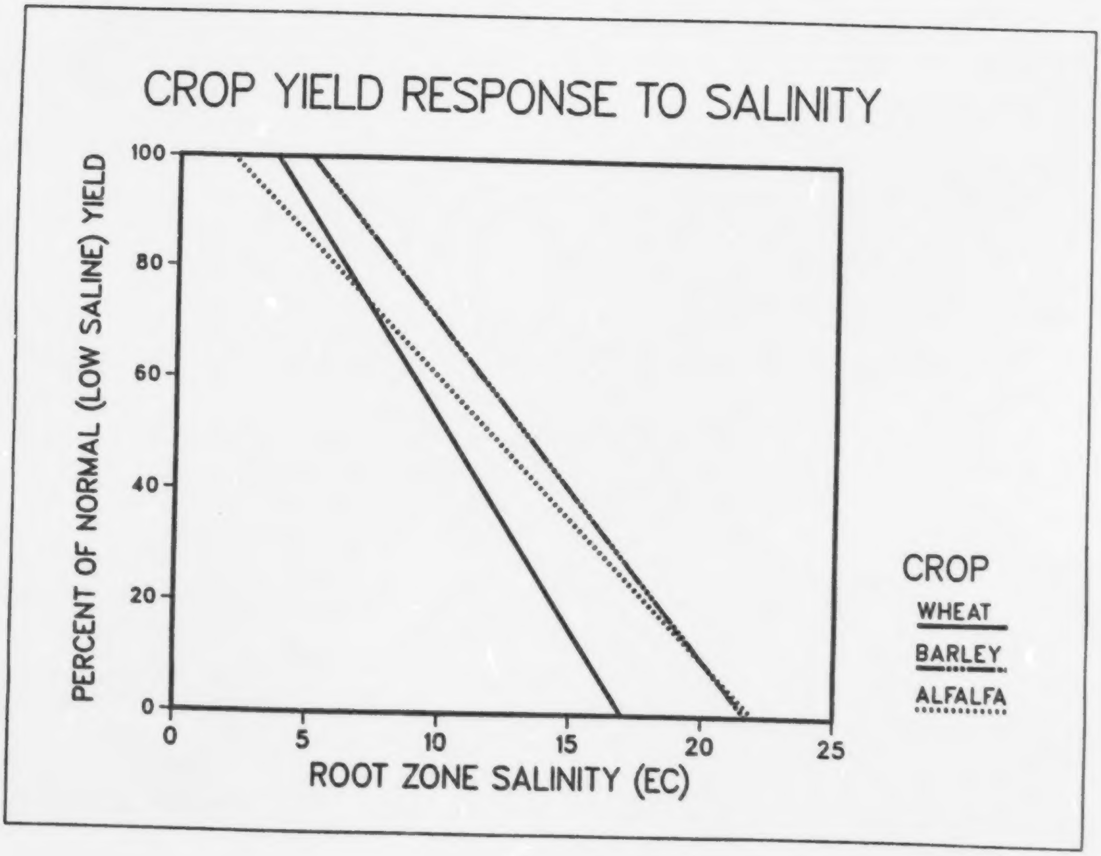
The analysis of the benefits associated with improved field efficiency after the elimination of an obstacle by drainage were extracted from Desjardins (1983).

2.2.1 Operating Sequence and Costs

For the purpose of this project the operating sequence was defined as the series of operations that is required to produce a specific crop in a specific farm situation. Identification of a specific farm situation is important since such things as the scale of operation will affect the type and size of equipment available for the different operations. This equipment will in turn affect the comparative time requirement and cost of each operation.

Because very little is known about the actual loss of inputs caused by the presence of an obstacle, this analysis does not attempt to include a cost figure for the loss of such inputs as fertilizer and seed. This analysis examines the extra costs of operations in terms of time, fuel and maintenance of equipment related to farming around a slough and the savings produced by removing the slough.

FIGURE 2



DERIVED FROM STOCHINSKY (1984)

Before dealing with specific parts of the calculation of field efficiencies, it is necessary to establish the assumptions on which these calculations were based.

These assumptions are:

(i) There is an overlap equal to 10% of the width of the piece of equipment used in a specific operation[1];

(ii) The headland is comprised of two passes in every location where such an operation is required;

(iii) All operations are done in a linear field pattern (see Figure 4); and

(iv) All calculations are based on a field of one ¼ section (2460ft x 2640ft).

For simplicity the calculation was separated into three parts:

° Turning time

° Headland time

° Linear cropping time

2.2.2 Turning Time

Two main factors are considered in the calculation of the time involved in turning.[2]

° Time to do one turn

° Number of turns required

---

[1] Chosen through consultation with Murray Green, Equipment Engineer, Engineering and Home Design Branch, Alberta Agriculture, Airdrie.

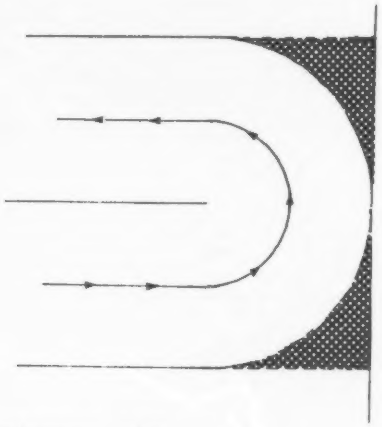
[2] It was assumed that when turning, half of the normal straight line speed is achieved and the operator is able to maintain the end of the equipment in a fixed position. (This latter assumption is close enough to reality and simplifies calculations to such an extent as to warrant its use).

The time to do one turn will be based on the width of the specific piece of equipment (see Figure 3) and the average speed attainable when turning. Equation 1.0 was obtained from this figure:

$$\frac{\quad x \text{ W.E.}}{2 \text{ x S.}/2} = \text{Turning Time (min)} \qquad (1.0)$$

FIGURE 3

= 3.1416



W.E. = Width of the specific piece of equipment (ft)
S. = Straight line speed (ft/min)

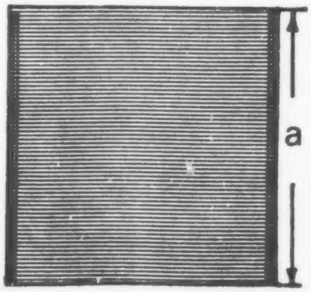
The number of turns will be affected by the size, number and location of the obstacles, and the width of the equipment. In the examples below the obstacle is assumed to be a 25 acre slough.

Case 1 For a field with no obstacle (as in Figure 4), or an obstacle on the fenceline the number of turns would be given by equation 2.1:

$$\begin{aligned} \# \text{ of turns} &= ((a/w.e.) - 1) \text{ x } 1.1 \\ &= ((2640/w.e.) - 1) \text{ x } 1.1 \qquad (2.1) \end{aligned}$$

W.E. = width of the equipment (ft)
1.1 = correction for overlap
a = 2640 (ft)

FIGURE 4



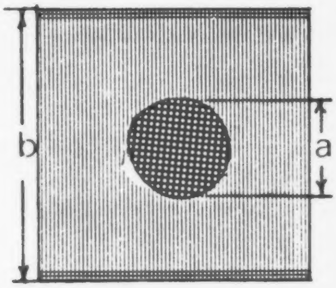
Turning Time with No Obstacles

Case 11 Where the obstacle is centrally located (Figure 5) there is a slight change in the equation, it will take the form of 2.2:

# of turns = ((b+a)/w.e.) x 1.1
= ((2640+1177.5)/w.e.) -1) + 1.1 (2.2)

b = 2640 ft.
a = 1177.7 ft.

FIGURE 5



Turning Time with Obstacle in the Center

In equation 2.2 the length (a) will be measured in the direction perpendicular to the general direction of travel of the equipment.

To obtain the amount of time required in turning, the time required for completing one turn is multiplied by the number of turns which are to be done.

2.2.3. Headland Time

A headland is an uncultivated land area at the end of a furrow or near a fence. Such an area would occur because of the imperfection of the coverage when one is turning (see Figure 4, shaded area).

To maximize the use of this land, the operator must repeat the operations on all the land affected by such a problem. This document has been based on the fact that two passes will be required on those areas to fully solve the problem.

In the cases being examined the length of the headland will equal the length of fence close to which an implement is turning, plus the cultivated circumference of the obstacle(s).

Equations are provided for the cases examined and Case II is illustrated in Figure 6 illustrates Case II.

Case I (No obstacle)

$Lh = 2 \times 2\ 2640 = 10560$ ft. (3.1)

Lh = Length of headland

Equation 3.1 deals with two full fence lengths with two passes each.

Case II (Central Location)

$Lh = 2 \times (2a + (b/\text{Speed correction factor}))$

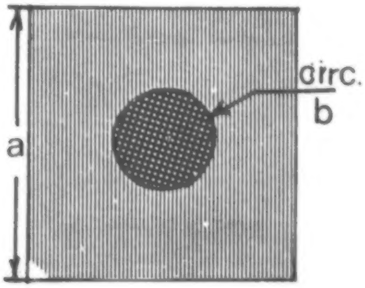
$Lh = 2 \times (2 \times 2640 + (3699.4))$ (3.2)

Where $a = 2640$ ft.

$b = 3699.4$ ft.

FIGURE 6

Headland with Obstacle in the Center



Where the obstacle is located on the fenceline the results will be intermediate between cases I and II. Lh will vary in accordance with the part of the circumference of the obstacle in contact with the field.

The time involved in cropping the headland would then be expressed by equation 4.0.

$Th = Lh/Ss$ (4.0)

Th = Time for headland (min)

Lh = Length of headland (ft)

Ss = Speed straight (ft.min)

2.2.4 Linear Cropping Time

First the area which will be covered by a linear travel pattern must be established. This will then permit the estimation of the time involved in the linear section of the run.

This area will be equal to the total field area, less the area covered by the obstacle, less the area covered by turns. Equation 5.1 and 5.2 illustrate cases with and without an obstacle.

Case I (No obstacle)

$$Al = Ta - Tu \qquad (5.1)$$

$$Tu = 2a \times W.e.$$

$$Al = (2740^2) - (5280\ W.e.)$$

Where

Al = Area covered by linear cropping pattern (ft^2)

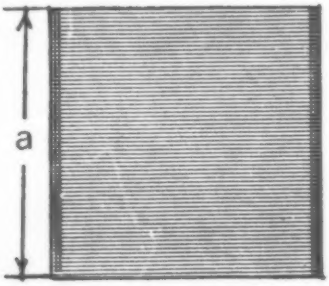
Ta = Total area (ft^2)

Tu = Turning area (ft^2)

$W.e.$ = Width of the equipment (ft)

FIGURE 7

Linear Cropping Time with no Obstacle



Case II (Central Location)

$Al = Ta - ((2a + b) \times W.e.) - Ao$

$Al = (2640^2) - (10212.4\ W.e.) - (1089000)$ (5.2)

Where

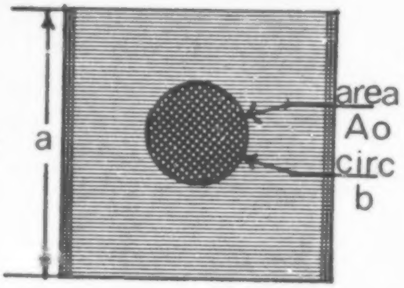
$a = 2460$ ft.

$b = 3699.4$ ft.

Ao = Area covered by obstacle

= 1089000 ft^2

FIGURE 8



Linear Cropping Time with Obstacle in the Center

In cases where the obstacle is on the fenceline, Al will be larger than in case II because this obstacle produces less turns thus less area is covered by turns.

The total time involved in cropping this area would be calculated from equation 6.0:

$Ts = ((Al/W.e.) \times 1.1)/Ss$ (6.0)

Where

Ts = Time straight (min)

Al = Area covered by linear pattern (ft^2)

Ss = Speed straight (ft/min)

1.1 = Correction factor for overlap.

To obtain the total time involved in farming this field, the three time components are summed, as in equation 7.0:

$Tt = Tu + Th + Ts$ (7.0)

Where

Tt = Total time (min)

Tu = Turning time (min)

Th = Time involved in headland (min)

Ts = Time involved in straight areas (min)

The location of the obstacle has an impact on the cost of production. This is shown in Table 1. Where the obstacle is not in contact with the boundary of the field, the impact on the cost of production is four to nine times larger than when the obstacle is at the boundary.

For the four crops studied, there is a drop in efficiency from 100% in the no obstacle situation, to a range of 96.2% to 99.4% with obstacles present (Table 2). The lowest loss of efficiency occurs with a permanent or semi-permanent crop (eg. pasture or hay crops). The smallest loss of efficiency occurs for alfalfa with the obstacle in the corner location. The row crop is the most efficient with a centrally located obstacle.

2.3 Costs of On-Farm Drainage

> Control and relamation of sloughs and wetland areas, can be accomplished through some form of surface drainage, giving a substantial possibility of increased crop production on the farm. However, agricultural drainage is characterized by a high degree of variability in costs and benefits between cases.
> Rousseau (1983)

Rousseau gathered information on 20 drainage projects, 16 of which were subsurface and 4 of which were surface drainage projects. Results shown in Tables 3 and 4 were extracted from his report. The wet area classification developed in Apedaile, Rapp and Desjardins, (1982) was used in his analysis (definitions are given in Table 3). There is the potential for substantial economies of scale in drainage projects. When the price per acre was regressed against the total area drained it was found that for every extra acre drained by the project the cost per acre decreased by $10.50. This regression had a correlation coefficient of -0.785. Other variables, such as the distribution of wet areas, also had an impact on the cost of drainage, hence not all the variance was explained by size of the drainage project.

Rousseau found that the costs per acre for surface drainage were substantially lower than for subsurface drainage. Average surface drainage costs were $121 per acre, being less than 25% of the average subsurface costs of $525 per acre. The existing drainage cost sharing agreement between the Province and farmers reduces the farmer's cost of surface drainage by another $92.86 to $28.16 per acre. However, only subsurface drainage is useful in the treatment of salinity, thus the lower cost of surface drainage techniques will have no impact on the economics of solving the salinity problem with drainage.

TABLE 1
COST OF PRODUCTION WITH AND WITHOUT OBSTACLES[1]

	Wheat	Barley	Alfalfa[2]	Sugar Beets
	$/acre			
No Obstacle	25.73	26.13	16.83	50.54
Obstacle in Center	26.65	27.12	17.29	51.72
Cost differential	(+.92)	(+.98)	(+.45)	(+1.18)
Obstacle in Corner	25.96	26.39	16.89	50.96
Cost differential	(+.23)	(+.26)	(+.06)	(+.42)

1. Based on a 25 acre obstacle
2. Mean annual cost per 5 year.

TABLE 2

EFFICIENCY PERCENTAGE BASED ON THE NO OBSTACLE CASE

	Wheat	Barley	Alfalfa	Sugar Beets
	% efficiency			
No Obstacle	100	100	100	100
Obstacle in Center	96.2	96.1	97.4	97.6
Efficiency Difference	(-3.8)	(-3.9)	(-2.6)	(-2.4)
Obstacle in Corner	99.1	98.7	99.4	99.3
Efficiency Difference	(-.9)	(-1.3)	(-.6)	(-0.7)

TABLE 3

SUBSURFACE DRAINAGE BY WET AREA CLASSIFICATION

Wet Area Classification	Number Of Projects	Definition	Mean Total Area Gained By Project (acres)	Mean Cost Per Acre Gained ($/acre)
1	3	Temporary Slough less than 5 acres	16.4	1,187
2	3	Permanent slough less than 5 acres	17.7	960
4	3	Temporary wetlands[1]	45.1	497
5	7	Permanent wetlands[1]	50.7	474
Average			37.0	523.01

[1] Wetlands are relatively large flat areas affected by excess water.

TABLE 4

COST OF SURFACE DRAINAGE BY INDIVIDUAL CASE

Case	Area Improved (acres)	Total Cost	Farmer's Share[1] Of Costs
		-----------$/acre	------------
1	380	$ 42	$11.48
2	123	$302	$54.83
3	150	$121	$33.00
4	40	$317	$86.39
Weighted mean	173.52	$121.12	$28.16

1. Under the program which covers surface drainage projects 27.27% of the costs are paid by the farmer.

3. THE MODEL

The model was separated into five major sections;

(i) The data;

(ii) The value of time lost;

(iii) Salinity and crop response;

(iv) Yearly costs and benefits; and

(v) Net present values.

This model was created on the IBM P.C. using the Lotus spread sheet softwear. This system efficiently generates the matrices required in the analysis with relative ease. (A copy of the program as displayed is present in Appendix 1).

3.1 The Data

Four main data sets were used. These were:

(i) Field operation and related variables;

(ii) Obstacle description size and distribution;

(iii) Crop information; and

(iv) Other information.

3.1.1 Field Operation

In this data matrix four main variables were required for each operation: the width (ft) of the machinery used; speed (ft/min); hourly cost[1]; and number of headland passes done.

A questionnaire survey done in cooperation with the District Agriculturalists and some farmers was used to estimate the real sequence of operations required in the production of all of the crops considered in the exercise.

In the matrix, a variable "X" was generated to segregate regular crop operations (where X equal to 1) from summerfallowing operations (where X becomes 0).

A further improvement of the model could be achieved by the generation of a specific data matrix for each crop thus permitting greater precision on the operation variables.

3.1.2 Obstacle Description

This data set provided the size (acres) and number of each type of obstacle considered in the analysis. Three obstacle types were considered with the differences in their location. Specifically they were: central; corner; and fenceline.

In this data set, space was allocated for a description of the obstacles which would still be present after drainage. This permitted the study of a partial solution or of solutions involving the concentration of a large slough into a smaller one (dugout).

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[1] The hourly charges used in this report were derived from Andruchow (1982).

3.1.3 Crop Information

In this matrix four sets of data were required for each of the crops considered[1]: optimum yield in the region considered (for a farm specific analysis these yields could be generated for specific agronomic variables); production cost; crop prices; and crop mix (the proportion of land assigned to each crop considered). Some space was also allocated to enter the cost of summerfallowing.

3.1.4 Other Information

This section included information such as:

(i) The initial Ec level. Because of mathematical constraints, the model does not accept an Ec of 0, therefore an Ec of 1 was used since it is smaller than the threshold level for all crops considered;

(ii) The amount of water in excess of rainfall to be applied during the life of the process. To increase the number of management opportunities tested, the project was broken down in three time spans; the first five years; the second five years; and the last 20 years.

---

[1] The required information was obtained from the following sources: Data about areas south of Red Deer were extracted from Dooley (1984); and data about areas north of Red Deer were obtained from Peter Woloshyn, Production and Resource Economics Branch, Alberta Agriculture. Because of data restrictions, information about the area south of Red Deer was based on agroclimatic zones, as defined in Figure 9, as opposed to soil types as with the northern areas.

(iii) The frequency with which a crop is taken off the area. This was applied to temporarily flooded areas which produce a crop in some years; and

(iv) The frequency of summerfallowing. This permitted the weighting of summerfallow charges.

3.2 The Value of Time Lost

The time lost because of an obstacle was determined by calculating the difference in the average time per acre required to farm a 1/4 section field with and without an obstacle. These times were calculated using an equation derived from the technique shown in Section 2.2. The additional cost created by the obstacle was then derived for the equipment sequences and hourly cost (given in Section 3.1.1.).

This calculation was repeated for each crop operation and each summerfallow operation. Production and summerfallow costs were then weighted by the frequency of summerfallowing to provide a weighted mean cost difference for a 1/4 section with and without an obstacle.

3.3 Yields

The equation presented in Section 2.1.1 was used to establish the Ec levels for the 30 years considered in this study.[1] The equations in Section 2.1.2 were used to establish the yields for the three crops used. Where the Ec level was below the threshold, full yields were automatically assumed. There were exceptions for years 1, 2 and 3 where low yields were used because of other productivity constraints during this "breaking in period". During the first three years 85, 90 and 95% of maximum yields were used.

---

[1] This equation does not take into account variations in soil types, because physical data was not available for various soil types.

3.4 Yearly Costs and Benefits

3.4.1 Increased Revenues

The increased revenues on the land previously affected by the problem were established from the products of the yields and prices weighted by the crop mix. This was then expressed as the average revenue increase per improved acre over the life of the project. The model used in establishing the yields permitted the occurrence of negative yields. A correction was made to convert these negative yields to zero.

3.4.2 Extra Pumping Costs

Normal water application rates were assumed for the last 20 years of the project. The extra water required to create leaching was determined for years 1 to 5 and for years 6 to 10 (difference between total application in each of these years and the normal rate). This extra water would generate extra pumping charges at the rate of $0.789 per acre inch of water applied.[1].

3.4.3 Efficiency Gains

The gain per acre improved resulting from the efficiency gains was estimated by dividing the weighted mean cost difference (calculated in Section 3.2) by the number of acres reclaimed.

---

1. Extracted from data supplied by Lloyd Andruchow, Production and Resource Economics Branch.

3.4.4 Production Costs

The mean cost of production was estimated by weighting the cost of production of each crop according to the crop mix. Summerfallow costs were also included in the appropriate proportion for the relevant crops.

3.4.5 Net Gain

The net value of the costs and revenues obtained in Section 3.4.1 to 3.4.4. provided an estimate of the yearly cash flow for the project. The calculation of the net gain assumed there were no crops on the affected area before drainage for the first scenario.

In a separate scenario an allowance was made for a crop in the years preceding the project at the yield level of year 1. A weighting factor was included to consider the flooding cycle when dealing with excess water problems without a salinity problem.

No allowance was made to eliminate production in years in which losses would occur (that is where new revenues would be less than new costs).

3.5 Net Present Value

An existing function of the Lotus system was applied to generate the net present value (NPV) of the project, or the value today of the net cash flows generated in the future. This was done for both scenarios: the first, assuming no crop before drainage; and the second, assuming a crop before drainage. The result of this analysis represented the maximum amount the producer would recover over the life of the project and therefore the maximum that should be invested in drainage.

Sensitivity analysis was done for different project lengths and cost of capital. NPV's were calculated for lives of 5, 10, 20 and 30 years with discount rates of 3.5, 5, 7, and 10%.

4. ANALYSIS: PROCEDURE AND RESULTS

4.1 Procedure

A number of cases were generated to represent different climatic, management and salinity situations, and to provide as complete a coverage of the province as possible. The data used in the analysis are presented in Table 5.

4.1.1 Climatic

Climatic variance affects the economics of drainage in two ways:

(i) Climate affects maximum yields attainable and influences certain management practices, such as crop mix. Cases were generated to take these variations into account. Analysis was based on the five agroclimatic regions south of Red Deer (see Figure 9) and the three major soil zones for the rest of the province; and

(ii) Where excess water is the problem and salinity is minimal climate will impact on the form of the flooding cycle. This cycle is represented by the frequency with which a producer could get a crop from the affected area in the pre-drainage period. To test this five different frequencies were used namely: 50%, 33%, 25%, 20% and 0%.

4.1.2 Management

This section was concerned with the water application levels needed to create leaching of the salts and thus to produce a solution to salinity under irrigated conditions. Four different water application practices were used to determine which practice would optimize returns. The extra labour required for higher levels of management (higher levels of water application) was not evaluated.

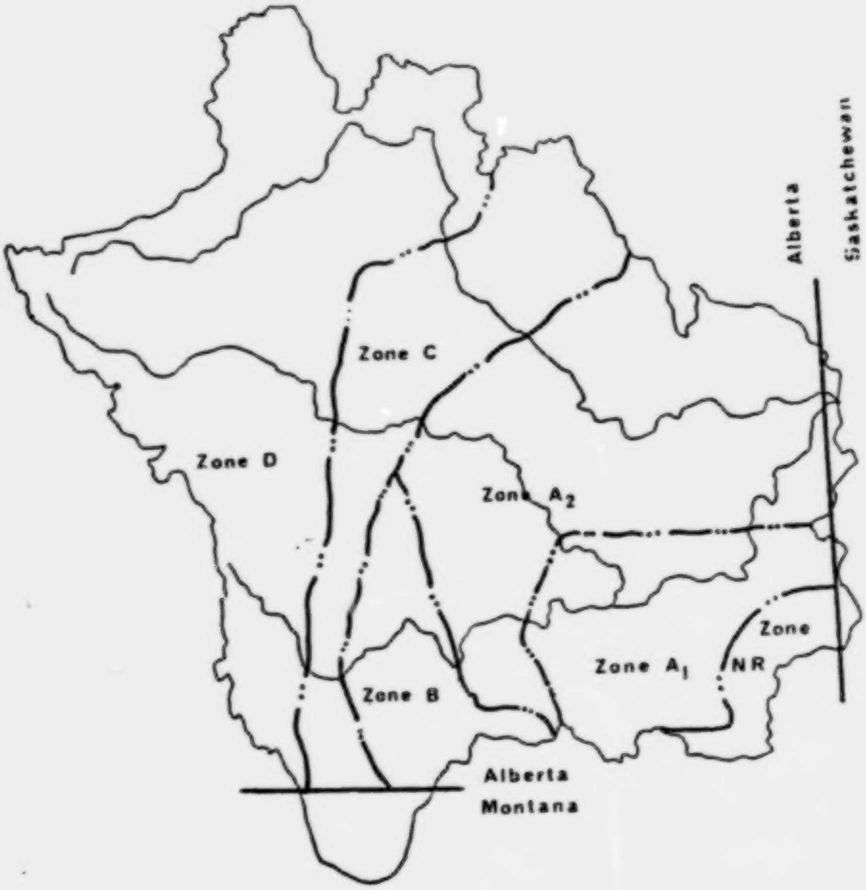
TABLE 5
YIELD AND PRODUCTION COSTS BY REGION AND CROP

Region or Soil Zone	Wheat			Barley			Alfalfa			Summer Fallow acre
	Yield Bus/acre	Prod. Cost $/acre	Crop mix	Yield Bus/acre	Prod. Cost $/acre	Crop mix	Yield Bus/acre	Prod. Cost $/acre	Crop mix	
Irrigation										
A1	85.38	122.88	0.60	96.30	113.50	0.20	2.95	100.20	0.20	---
A2	85.50	122.88	0.40	96.10	113.50	0.30	2.95	100.20	0.30	---
B	89.10	122.88	0.30	97.00	113.50	0.35	3.22	100.20	0.35	---
C	80.00	122.88	0.10	95.20	113.50	0.35	3.07	100.20	0.55	---
D	83.90	122.88	0.25	95.70	113.50	0.30	3.10	100.20	0.45	---
Dryland										
A1	24.70	54.33	0.75	40.90	54.33	0.15	1.20	26.23	0.10	4.93
A2	25.30	51.06	0.70	40.50	51.15	0.20	1.02	25.04	0.10	4.98
B	29.00	65.00	0.50	46.50	68.01	0.40	1.19	25.74	0.10	6.43
C	29.00	60.36	0.60	43.90	62.99	0.30	1.17	25.74	0.10	5.63
D	36.00	84.39	0.20	50.00	86.90	0.60	1.19	35.95	0.20	6.52
	Wheat			Barley			Canola[1]			
Dark Brown	33.90	60.72	0.55	58.00	59.84	0.30	24.50	48.44	0.15	5.97
Black	36.00	62.66	0.33	58.30	61.39	0.33	24.90	49.94	0.33	---
Luvisol (Peace River)	31.10	58.43	0.20	40.70	55.24	0.50	18.40	44.70	0.30	5.97

1. Canola for Dark Brown, Black and Luvisol, yields in bus/acre.

FIGURE 9

SOUTH SASKATCHEWAN RIVER BASIN - AGROCLIMATIC ZONES


Alberta
Saskatchewan
Zone C
Zone D
Zone A$_2$
Zone A$_1$
Zone NR
Zone B
Alberta
Montana

Zone	Characteristics	Zone	Characteristics
A1	> 1650 Heat Units (5°C) > 140 Day Growing Season (-2°C) 250-300 mm Moisture Deficit	C	1150-1350 Heat Units (5°C) 120-140 Day Growing Season 150-250 mm Moisture Deficit
A2	1350-1650 Heat Units (5°C) 120-140 Day Growing Season (-2°C) 250-300 mm Moisture Deficit	D	< 1200 Heat Units (5°C) < 120 Day Growing Season < 150 mm Moisture Deficit
B	1350-1650 Heat Units (5°C) 120-140 Day Growing Season (-2°C) 200-250 mm Moisture Deficit	NR	Not Rated

4.1.3 Salinity

The impact of initial salinity on the economics of drainage was tested at four levels: Ec of 20, 15, 10 and 1. The minimum level (Ec = 1) represented the no salinity situation. Reclamation rates for barley under irrigated and dryland conditions, and different levels of water application or precipitation are given in Table 6.

TABLE 6
RECLAMATION RATE[1]
FOR BARLEY[2]

	Years			
	Water Application			
Initial Ec	75-25	75-50-25	50-25	25
	cm/acre			
Irrigation				
20	8	7	13	18
15	5	5	9	14
10	3	3	5	9
	Precipitation			
	35	25	15	
Dryland				
20	13	18	30	
15	10	14	24	
10	7	9	15	

1. Time period required to regain full production.

2. Barley was selected because it is a wide spread crop and fairly resistant to salintiy.

4.2 Results

Results are presented in Tables 7 to 10. Each scenario was tested against the drainage costs of $523 per acre for subsurface drainage and $121 per acre for surface drainage which were presented earlier. The base case assumed a real discount rate of 5% and a 10 year project life (for repayment).

4.2.1 Irrigation with Salinity

Results for irrigated saline conditions in southern Alberta are presented in Table 7. Assuming no previous crop, the most advantageous management options were those with larger amounts of water applied to the problem area in the first five years. These options exceeded the benefits of lower water management techniques by almost two fold in the high salinity cases for all regions. Assuming no previous crop, all regions showed losses under the high Ec and low management approach. This loss signified that not only would the farmer not pay for the drainage system, but he would not even cover the cost of production. Regions C and D also showed returns below the cost of sub-surface drainage with higher water management levels and the high Ec level.

All regions had better returns under the low Ec and high management approach. Testing returns against the cost of sub-surface drainage showed that under the low Ec and high water management approach, returns were sufficient to cover drainage costs in all cases. Where there may have been a previous crop, most cases became economical except at the low management and low Ec level. This is because under the low Ec level, a crop would have been produced before drainage generating some profit. All other cases depicted situations where the previously grown crop would generate negative returns in relation to potential returns after drainage.

Some care should be used in adopting the previous crop assumption, especially in cases of high salinity. The low yields attainable prior to drainage would have made crop production quite improbable.

TABLE 7
DRAINAGE OF IRRIGATED SALINE AREAS: NET PRESENT VALUE RESULTS[1]

Water Applied[2]	EC Level					
	20		15		10	
	Net Present Value[3]					
cm/acre	NPC	PC	NPC	PC	NPC	PC
	$/acre					
Region A1						
75-25-25	670.39	1569.47	1061.88	1457.09	1441.95	903.77
75-50-25	686.05	1585.14	1045.57	1440.78	1416.95	878.76
50-25-25	316.42*	1154.58	820.19	1154.47	1359.65	760.55
25-25-25	-161.80*	615.43	451.79*	725.14	1143.26	483.23*
Region A2						
75-25-25	580.54	1417.13	919.26	1245.36	1243.98	773.23
75-50-25	587.29	1423.88	902.49	1228.39	1219.85	749.11
50-25-25	284.23*	1059.90	724.25	989.42	1178.34	646.68
25-25-25	-123.62*	591.12	414.81*	619.06	1004.99	412.41*
Region B						
75-25-25	596.06	1395.45	922.21	1186.26	1232.90	737.48
75-50-25	599.93	1399.33	905.96	1170.00	1209.49	714.08
50-25-25	315.68*	1054.16	741.12	944.24	1170.70	614.36
25-25-25	-74.22*	603.33	447.83*	590.02	1010.27	393.00*
Region C						
75-25-25	416.52*	1150.21	671.42	901.45	912.50	571.80
75-50-25	411.75*	1145.44	656.14	886.17	890.77	550.07
50-25-25	214.79*	887.55	547.10	716.20	866.67	465.04*
25-25-25	-75.52*	536.32	335.22*	443.40*	757.81	295.26*
Region D						
75-25-25	500.66*	1282.12	798.20	1072.97	1082.78	674.98
75-50-25	505.29*	1283.76	782.83	1057.60	1060.17	652.38
50-25-25	251.96*	972.50	637.51	851.35	1025.07	556.35
25-25-25	-96.47*	563.15	377.37*	530.28	882.88	353.23*

1. 5% discount rate and 10 year project.

2. Application rates during years 1 to 5; 6 to 10 and 11 to 30.

3. NPC indicates no previous crop; PC indicates a previous crop.

* Indicates scenarios which do not cover average sub-surface drainage costs (see Section 2.3).

4.2.2 No Salinity Under Irrigation

As shown in Table 8, under non-saline irrigated conditions all cases were shown to be economical in relation to the benchmark sub-surface drainage cost of $523 per acre. All cases would be greatly advantageous where surface drainage was undertaken. However, some problems may be caused by the drainage ditch through the impact on field operations.

4.2.3 Dryland Salinity

Sub-surface drainage of dryland saline areas were tested under three rainfall levels. The results in Table 9 show that none of these projects would pay. The net returns in all cases were less that the cost of sub-surface drainage. Region C went from the worst case under irrigation, to the best case under dryland conditions. This is because of higher dryland yields in this region. This analysis is based on normal weather conditions, particularly precipitation. It does not take into account the possibility of major changes in the existing weather pattern which may make certain dryland cases become economical. For example, a heavy rainfall could produce the leaching of salts necessary to reduce the Ec level at a rate similar to that of a high water application rate under irrigated conditions.

4.2.4 Non-Saline Dryland Conditions

The results for drainage of non-saline dryland areas are given in Table 10. The cost of underground drainage would be prohibitive where there was a 50% chance of getting a crop without drainage. This was also the case in most regions where a crop would be produced once in three years. The Peace River area (Luvisols) was the only region with a return too small in all cases to justify underground drainage. Most other regions would cover the cost of sub-surface drainage where there was a 25% or lower chance of a crop being produced prior to drainage. In all cases the returns would justify the cost of surface drainage.

TABLE 8
DRAINAGE OF NON-SALINE IRRIGATED AREAS: NET PRESENT VALUE RESUTLS[1]

Water Applied[2]	Net Present Value Proportion of Time a Crop was Produced 0.333	0.25	0.2	0
	($/acre)			
Region A1				
25	1260.07	1378.72	1450.21	1736.13
Region A2				
25	1095.33	1197.27	1285.67	1504.31
Region B				
25	1082.11	1182.85	1243.54	1486.29
Region C				
25	833.72	909.22	954.70	1136.62
Region D				
25	971.16	1060.61	1114.48	1330.01

1. 5% discount rate and 10 year project.

2. Normal irrigation rate.

TABLE 9
DRAINAGE OF DRYLAND SALINE AREAS:*
NET PRESENT VALUE RESULTS[1]

Precipitation[2]	EC Level					
	20		15		10	
	Net Present Value[3]					
cm/acre	NPC	PC	NPC	PC	NPC	PC
	$/acre					
Region A1						
35	-17.07	155.35	80.89	165.58	234.59	153.87
25	-64.63	107.79	43.82	128.50	171.63	90.91
15	-117.83	54.59	-0.55	84.13	136.81	56.09
Region A2						
35	0.44	159.05	99.35	166.19	257.29	158.12
25	-47.39	111.23	62.14	128.98	192.09	92.91
15	-101.07	57.54	17.61	84.44	155.48	56.30
Region B						
35	-15.99	188.82	94.24	180.02	283.58	189.53
25	-68.27	136.54	53.93	139.70	203.08	109.03
15	-127.93	76.89	5.70	91.47	155.03	60.98
Region C						
35	-12.85	235.36	130.23	238.00	327.29	197.31
25	-81.55	166.66	76.94	184.70	260.56	130.59
15	-159.12	89.09	13.16	120.93	210.60	80.62
Region D						
35	-49.38	275.43	98.70	232.01	308.89	210.43
25	-117.67	207.13	46.75	180.06	235.47	137.01
15	-197.48	127.33	-15.42	117.89	177.05	78.59

1. 5% discount rate and 10 year project.

2. Various natural precipitation levels.

3. NPC indicates no previous crop; PC indicates a previous crop.

* No scenarios covered average sub-surface drainage costs.

TABLE 10
DRAINAGE OF NON-SALINE DRYLAND AREAS: NET PRESENT VALUE RESULTS[1]

Region	Net Present Value Proportion of Time a Crop was Produced 0.5	0.33	0.25	0.2	0	
	---------$/acre	---------	---------	---------	---------	
Region A1	386.96*	482.29*	529.68	558.23	672.41	
Region A2	399.15*	489.12*	547.30	576.93	695.45	
Region B	432.33*	537.96	590.45	622.08	748.58	
Region C	406.25*	503.52*	551.86	580.98	697.48	
Region D	378.71*	464.91*	507.76*	533.57	636.81	
Dark Brown	484.83*	602.18	660.51	695.65	836.20	
Black	379.26*	466.49*	507.53*	533.18	635.80	
Luvisols (Peace)		299.65*	368.85*	403.24*	423.96*	506.83*

1. 5% discount rate and 10 year project.

4.3 Sensitivity Analysis

In this section the impact of changes in some of the economic variables used in the previous analysis were tested.
These variables were:

(i) Life of project;
(ii) Cost of capital;
(iii) Cost of production (inclusion of fixed cost); and
(iv) Exclusion of crop insurance costs.

This analysis was done for region C for both irrigated and dryland conditions. Region C was chosen since it was the most marginal in many cases. The sensitivity analysis would indicate under what conditions sub-surface drainage would become feasible in Region C. Usually where sub-surface drainage was feasible in Region C it would be feasible in the other regions. Results are given in Tables 11 to 16.

4.3.1 Life of Project

Under almost all conditions (irrigated and dryland, saline and non-saline) a reduction of the project life from 10 years to 5 years made sub-surface drainage economically infeasible (see Tables 11 and 12). The single exception was irrigated non-saline areas with no chance of a crop prior to drainage. These results indicated that where drainage costs would be recovered in 10 years under high water management levels and low to medium Ec, these same costs would not be recoverable in 5 years. Drainage of dryland saline areas was not economical either with a 10 or 5 year project life. However, drainage costs of non-saline dryland areas (with crops produced 20% of the time prior to drainage) and non-saline irrigated areas could be recovered after 10 years but not after 5 years. Sub-surface drainage of irrigated non-saline areas with no chance of a crop prior to drainage remained feasible. Under non-saline conditions surface drainage always paid.

TABLE 11
SENSITIVITY ANALYSIS: PROJECT LIFE, SALINE AREAS
REGION C

	EC Level					
Water Applied	20		15		10	
	Net Present Value[1]					
cm/acre	NPC	PC	NPC	PC	NPC	PC
	$/acre					
Irrigated						
5% Discount Rate, 5 Year Project*						
75-25-25	-21.13	390.25	185.71	314.69	395.38	204.36
75-50-25	-21.13	390.25	185.71	314.69	395.39	204.36
50-25-25	-96.95	280.26	137.31	232.13	379.94	154.75
25-25-25	-196.19	146.85	68.54	129.20	345.48	86.13
5% Discount Rate, 20 Year Project						
75-25-25	1126.41	2310.52	1401.76	1773.01	1653.86	1103.99
75-50-25	1146.84	2330.96	1397.43	1768.68	1632.31	1082.45
50-25-25	862.62	1948.41	1244.81	1517.73	1597.46	949.27
25-25-25	437.41*	1424.87	954.84	1129.07	1456.64	710.12
5% Discount Rate, 30 Year Project						
75-25-25	1581.63	3042.28	1857.00	2314.95	2109.10	1430.83
75-50-25	1602.08	3062.72	1852.67	2310.62	2087.56	1409.28
50-25-25	1313.91	2653.25	1699.89	2036.55	2052.70	1253.14
25-25-25	873.22	2091.28	1402.85	1618.22	1911.77	990.92
Dryland						
5% Discount Rate, 5 Year Project*						
35	-82.21	56.96	11.71	72.13	120.96	48.09
25	-104.28	34.84	-6.60	53.82	108.76	35.88
15	-123.55	15.62	-26.66	33.77	95.39	22.51
5% Discount Rate, 20 Year Project						
35	302.19*	702.78	525.22	699.14	776.84	567.07
25	103.36*	503.94*	351.06*	524.99	657.30	447.52*
15	-88.78*	311.81*	158.84*	332.77*	455.62*	245.84*
5% Discount Rate, 30 Year Project						
35	578.64	1072.78	801.70	1016.24	1053.32	794.56
25	357.97*	852.11	627.07	841.61	933.77	675.01
15	24.42*	518.56*	318.49*	533.03	720.17	461.41*

1. NPC indicates no previous crop, PC indicates a previous crop.
2. Indicates scenarios which do not cover average sub-surface drainage costs.

TABLE 12
SENSITIVITY ANALYSIS: PROJECT LIFE, NON-SALINE AREAS
REGION C

	Net Present Value				
	Proportion of Time a Crop was Produced				
	0.5	0.33	0.25	0.2	0
	----$/acre)----				
Irrigated					
5% Discount Rate, 5 Year Project					
		436.14*	478.48*	503.98*	605.98
5% Discount Rate, 20 Year Project					
		1389.30	1511.15	1584.55	1878.16
5% Discount Rate, 30 Year Project					
		1730.38	1880.68	1971.23	2333.41
Dryland					
5% Discount Rate, 5 Year Project*					
	211.91	266.45	293.56	309.89	375.20
5% Discount Rate, 20 Year Project					
	677.81	834.80	912.82	959.83	1147.83
5% Discount Rate, 30 Year Project					
	844.53	1038.18	1134.42	1192.40	1424.31

* Indicates scenarios which do not cover average sub-surface drainage costs.

Extending the project life or the period for repayment to 20 years made most cases under irrigation economically feasible. This applied even at high Ec and low water application rates, with the exception of Ec 20, the lowest water application (25-25-25) and no previous crop. Extending the project life to 30 years made this last scenario feasible.

This analysis implied that with a 30 year project life and at a sub-surface drainage cost of $523 per acre, the expected increased returns would be sufficient to cover drainage costs under all irrigated conditions considered previously. Even with a 20 year project life most scenarios would be feasible. However, farmers should not expect to recover all drainage costs in 5 years.

Under dryland saline conditions, extending the project life to 20 years only made drainage feasible under certain conditions. These were high precipitation levels of 35 cm/acre (except with Ec 20 and no previous crops) and two cases with 25 cm/acre. Extension to 30 years made more cases feasible but at the low precipitation rate of 15 cm/acre only two cases were feasible. Under non-saline dryland conditions drainage became feasible with a 20 year project life for all cases. Cases which had 50% or 33% chance of crops produced prior to drainage were not economical with a 10 year life.

4.3.2 Cost of Capital

The stability of the results were tested at lower and higher discount rates (see Tables 13 and 14). As expected, the returns were all slightly higher at a 3.5% discount rate, however, the number of cases which were feasible at 5% did not change significantly. For irrigated saline conditions, only previously feasible cases remained feasible at 3.5% and four more cases became infeasible at the 7% rate. All cases under irrigated non-saline conditions were feasible at each discount rate.

Drainage of saline dryland areas remained infeasible at 3.5% and 7% discount rates. For non-saline dryland areas the results were very

TABLE 13
SENSITIVITY ANALYSIS: DISCOUNT RATE, SALINE AREAS
REGION C

Water Applied	EC Level					
	20		15		10	
	Net Present Value					
cm/acre	NPC	PC	NPC	PC	NPC	PC
	$/acre					
Irrigated						
3.5% Discount Rate, 10 Year Project						
75-25-25	474.66*	1264.89	742.69	990.40	994.76	627.81
75-50-25	469.56*	1259.77	725.70	973.46	970.46	603.51
50-25-25	253.51*	978.11	606.54	788.68	944.21	511.65*
25-25-25	-65.57*	593.41	373.40*	489.91*	824.42	326.21*
7% Discount Rate, 10 Year Project						
75-25-25	349.82*	1017.18	588.90	798.13	816.63	506.73*
75-50-25	345.45*	1012.81	575.58	784.82	797.86	487.96*
50-25-25	170.75*	782.69	478.41*	632.23	776.30	410.99*
25-25-25	-86.05*	470.47*	291.29*	389.69*	680.24	259.51*
Dryland						
3.5% Discount Rate, 10 Year Project*						
35	-6.26	261.07	146.63	262.70	359.38	219.39
25	-82.00	185.34	88.01	204.08	284.65	144.65
15	-167.98	99.35	17.68	133.76	229.16	89.17
7% Discount Rate, 10 Year Project*						
35	-20.02	205.75	111.42	209.45	290.23	172.00
25	-80.58	145.18	64.31	162.33	232.61	114.39
15	-148.44	77.33	8.10	106.13	188.98	70.75

1. NPC idicates no previous crop, PC indicates a previous crop.

* Indicates scenarios which do not cover average sub-surface drainage costs.

TABLE 14
SENSITIVITY ANALYSIS: DISCOUNT RATE, NON-SALINE AREAS
REGION C

	Net Present Value Proportion of Time a Crop was Produced 0.5	 0.33	 0.25	 0.2	 0
	$/acre				
Irrigated					
3.5% Discount Rate, 10 Year Project		901.73	983.05	1032.03	1227.97
7% Discount Rate, 10 Year Project		754.07	822.73	864.10	1029.58
Dryland					
3.5% Discount Rate, 10 Year Project	439.46*	544.22	596.29	627.66	753.13
7% Discount Rate, 10 Year Project	367.35*	455.82*	499.80*	526.29	632.25

* Indicates scenarios which do not cover sub-surface drainage costs.

similar at each discount rate. At the 3.5% rate, drainage was infeasible only where there was a 50% chance of a crop before drainage was infeasible; at 5% this was extended to the 33% chance case and at 7% to the 25% chance case.

The results indicated that the feasibility of drainage is not very sensitive to the changes in discount rates examined.

4.3.3 Cost of Production - Fixed Costs Included

In the base analysis cost of production estimates for the drained area included variable costs only. It was assumed that all fixed costs were covered by the already cropped areas of the farm. Thus, no fixed costs were charged against farming the drained area.

In this sensitivity analysis, fixed costs were included to establish under what conditions and to what extent the net benefits of drainage could contribute towards fixed costs. Again the analysis was restricted to region C. The fixed costs increased irrigated costs of production by approximately 43%; and dryland costs of production by 90%.

With irrigated saline conditions and the base cost assumption, negative returns were shown in only one instance (Ec 20, lowest water application and no previous crop). With the inclusion of fixed costs only two more cases showed negative returns (Table 15). However, the number of cases not covering the cost of sub-surface drainage increased from eight to fourteen.

Under most situations with no previous crop, the net benefits resulting from drainage would not be high enough to cover both drainage and fixed costs. However, at low and medium Ec levels (Ec 10 and 15), the sub-surface drainage costs would be covered. Where there was a previous crop, the results from including fixed costs were unchanged from the base case (three cases did not cover sub-surface drainage costs). This is because fixed costs would be the same before and after drainage and would not affect the incremental returns from drainage.

TABLE 15
SENSITIVITY ANALYSIS: SALINE AREAS[1], COST OF PRODUCTION
REGION C

Water Applied	EC level[2]					
	20		15		10	
	Net Present Value					
cm/acre	NPC	PC	NPC	PC	NPC	PC
	$/acre					
Irrigated, Fixed Costs Included						
75-25-25	53.88*	1150.21	308.97*	901.45	550.21	571.80
75-50-25	49.11*	1145.44	293.68*	886.17	528.48	550.07
50-25-25	-148.04*	887.55	184.54*	716.20	504.34*	465.04*
25-25-24	-438.61*	536.32	-27.53*	443.40*	395.40*	295.26*
Dryland, Fixed Costs Included*						
35	-182.01	235.36	-38.93	238.00	158.13	197.31
25	-250.71	166.66	-92.22	184.70	91.40	130.59
15	-328.28	89.09	-156.00	120.93	41.44	80.62
Irrigated, Crop Insurance Excluded						
75-25-25	445.58*	1150.21	700.48	901.45	941.56	571.80
75-50-25	440.80*	1145.44	685.19	886.17	919.83	550.07
50-25-25	243.84*	887.55	576.15	716.20	895.72	465.04*
25-25-25	-46.46*	536.32	364.28*	443.40*	788.52	295.26*
Dryland, Crop Insurance Cost Excluded*						
35	17.29	235.36	160.37	238.00	357.43	197.31
25	-51.92	166.66	107.07	184.70	290.70	130.59
15	-128.98	89.09	43.30	120.93	240.73	80.62

1. 5% discount rate and 10 year project.

2. NPC indicates no previous crop, PC indicates a previous crop.

* Indicates scenarios which do not cover sub-surface drainage costs.

For dryland saline conditions sub-surface drainage was not feasible even without the inclusion of fixed costs. The situation worsened for cases where there was no previous crop, all but one case showed negative returns. The cases with a previous crop remained unchanged.

Under non-saline irrigated conditions the inclusion of fixed costs made drainage infeasible where there was a 50% frequency of producing a crop without drainage. Under all other crop frequency levels the net benefits covered both fixed costs and drainage costs with irrigation (Table 16).

With non-saline dryland conditions net benefits of drainage covered variables costs and sub-surface drainage costs where there was a 25% or lower frequency of a crop prior to drainage. When fixed costs were included in the analysis, sub-surface drainage would not be covered under any previous crop frequency scenario. However, surface drainage remained feasible in all cases.

4.3.4 Crop Insurance Costs Excluded

Crop insurance costs were included in the original base analysis. However, this is not a true economic cost and was therefore excluded in this sensitivity analysis to examine the impact on the economic feasibility of drainage. These costs represented less than 5% of the total cost of production for irrigated crops and 9% of total dryland costs. The analysis was done for region C. Since these costs form less than 10% of total costs in all cases the impact was not expected to be too major.

As with the inclusion of fixed costs, there was no impact for saline areas where there was a previous crop (see Table 15). Under saline conditions where there was no previous crop the impact was minimal. Negative returns were reduced somewhat but where sub-surface drainage costs were not covered in the base analysis, the situation was unchanged with the removal of crop insurance costs.

TABLE 16
SENSITIVITY ANALYSIS: NON-SALINE AREAS[1], COST OF PRODUCTION
REGION C

	Net Present Value Proportion of Time a Crop was Produced				
	0.5	0.33	0.25	0.2	0
	$/acre				
Irrigation, Fixed Costs Included	500.77*	592.16	637.57	664.93	774.38
Dryland, Fixed Costs Included	321.66*	390.69*	424.99*	445.65*	528.31
Irrigation, Crop Insurance Cost Excluded	696.34	853.10	931.01	977.95	1165.68
Dryland, Crop Insurance Cost Excluded	421.31*	523.62	574.46	605.09	727.61

1. 5% discount rate and 10 year project.

* Indicates scenarios which do not cover sub-surface drainage costs.

The results indicated that for irrigated saline conditions 5% reductions in costs were not large enough to change the results. In addition to excluding crop insurance costs, reductions of at least another 15% would be required to make most previously infeasible cases feasible. In a few instances, with low water application levels, even a 20% reduction in costs would not make sub-surface drainage feasible. For dryland saline conditions 9% reductions in costs did not make sub-surface drainage feasible. Much larger reductions in production and/or drainage costs in excess of 70% would be required to make sub-surface drainage of dryland saline areas economically feasible.

For non-saline conditions, sub-surface drainage became marginally feasible with the cost reductions even where there was a 33% chance of a crop with no drainage. It did not become feasible at the 50% level. The marginal increase in net benefits due to the exclusion of crop insurance costs was not sufficient to affect this last case.All cases showed surface drainage to be feasible with or without the inclusion of crop insurance costs.

5. QUALITATIVE COSTS AND BENEFITS

5.1 Benefits

In this section the qualitative benefits of slough drainage are discussed. There are several gains related to drainage which do not have monetary values attatched to them and there are several benefits which collectively contribute to increased crop yields, but individually have no quantitative evaluation.

5.1.1 Effects on Soil Structure

Whenever there is rainfall or runoff in excess of evapotranspiration, there will be deterioration of the soil structure. Different degrees of deterioration will take place depending on the length of time the water remains in the soil.

For soil to have a good drainage system, it must have a structure which contains cracks and fissures to great depths to provide channels for drainage. For a soil to have satisfactory water conductivity there must be an adequate number of connecting pathways of sufficient diameter (over 0.1 mm). Normal wetting and drying cycles produce the shrinking and swelling action needed to create cracks. Where the soil is saturated this action is substantially reduced. The longer the excess water remains in the soils, the worse the soil structure gets. With the water channels reduced, or destroyed completely, the only way the water can be removed is through evaporation.

Soil structure is adversely affected if tilling or harvesting operations are performed when the soil is too wet. With the size and weight of equipment used currently, the soil is easily compacted when excess moisture is present. When this happens the drainage channels are disrupted causing the potential for greater water build up.

5.1.2 Soil Aeration

For a soil to be productive, a minimum of 10% porosity is required (Kohke, 1977). The soil needs a minimum of one percent oxygen for the plant roots to have proper respiratory activity. When the large pores are filled with water, gas diffusion decreases rapidly. With the reduction of the amount of oxygen in the soil the ability of the roots to absorb nutrients decreases and root transpiration ceases. As the amount of oxygen decreases the amount of carbon dioxide and the concentration of ethylene increases. Also high concentrations of manganese may occur which greatly reduce root growth. When the oxygen is removed from the soil, anaerobic conditions occur. If anaerobic conditions occur, denitrification may result. In the denitrification process, the nitrate ions in the soil are converted to nitrogen gas. This decreases the amount of nitrogen available to the plant. Drainage is vital where water saturates the soil reducing aeration.

5.1.3 Water Holding Capacity

Drainage removes water from the soil but at the same time allows the soil to store more water. The way that this happens, is that when the soil is drained, the physical structure of the soil is improved. When the structure is improved, the soil is able to store more moisture. Pore spaces smaller than 0.05 mm. are able to hold water against gravity through cohesive forces. Through the shrinking and swelling activities of a properly drained soil the soil structure continues to improve, water holding capacity also increases. Plants are then able to root deeper into the soil to find more moisture and nutrients, thus increasing yields.

5.1.4 Timeliness of Operations

Excess moisture delays planting on poorly drained soils. One of the reasons for a late planting date is low soil temperature. The specific heat of water is 1 cal/g and for soil it is 0.2 cal/g. If the soil porosity is 50%, the volumetric heat capacity is 0.50 X 2.65 X 0.2 = 0.26 cal/cm^3. If only one half the pore space is filled with water, the volumetric heat capacity would be $0.26 + (0.25 \times 1.0) = 0.51$ cal/cm³[1]. Therefore it would take twice as long to raise the temperture of a soil 50% saturated 1°C as it would a dry soil at 1°C.

Drainage increases the temperature of the surface layers of the soil by lowering the specific heat. The difference can be seen in Table 17 where poorly drained soils are 1.4°C to 7°C lower in temperature than well drained soils.

TABLE 17

SOIL TEMPERATURE EFFECTS OF DRAINAGE

Date	Air Temp °C	Well Drained Soil °C	Pooly Drained Soil °C	Difference
April 24	15.8	19.2	12.2	7.0
25	17.8	21.0	14.4	6.6
26	7.2	10.0	6.7	3.3
27	11.7	12.8	10.4	2.4
28	7.2	8.3	6.9	1.4

Source: Michigan Agriculture College, Technical Building # 26.

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[1] Figures taken from Irwin 1979.

Germination is greatly reduced at low soil temperatures. Microbial activity declines and seeds may also rot before sprouting.

If a soil is properly drained, the farmer has a greater choice of varieties of crops to plant, because of the increased soil temperature. Table 18 shows the difference in yields depending upon the maturity time of various varieties of barley.

TABLE 18

VARIETAL YIELDS BY TIME OF MATURITY

Barley Variety	Time to Maturity South	Time to Maturity North	Yield Index South	Yield Index North
Galt	n.a.	n.a.	100	100
Johnston	102	105	111	116
Klondike	99	100	107	109
Bononza	99	99	104	96
Leduc	100	100	122	109
Empress	100	100	113	113

Source: Agriculture Canada.

With well drained soils, many advantages are opened up to farmers. There is a wider range of crops that can be produced and more varieties to choose from. This allows the farmer to achieve optimum benefits from that cultivable area. Crops with longer growing seasons can be produced which tend to have better yields.

When sloughs or wetlands are flooded in the spring, planting dates are set back. With very late seeding the crop encounters the short days of late fall during the maturity period, and the number of days from seeding to harvest increases.

For barley in the Peace River area, seeding much after June 1st often results in loss of crop by fall frost. In southern Alberta crops planted as late as June 20th often mature without frost damage, while planting much after June 10th in central Alberta is often hazardous (McLelland 1983).

Not only are fall frosts of great concern, but damage due to waterfowl in some areas causes large losses in crops. If a crop is planted early, then the chance of waterfowl damage is reduced, but if planting is delayed due to poorly drained soils, the chance of waterfowl damage rapidly increases. When waterfowl get into a field that is swathed, the crop can be almost completely destroyed in a matter of days. Also when there are large sloughs or wetlands in a field, waterfowl are attracted by the water to pond there, making it very convenient to damage the rest of the crop in the field.

5.1.5 Efficiency of Machinery

Regardless of whether there are 10 acres or 1000 acres to plant the same number of days are available to put in the crop. Waiting for sloughs or wetlands to dry out reduces the number of days to plant a crop. Therefore over-investment in machinery may be needed to ensure that the entire crop is harvested in the fall. By having well drained soil the land can be worked as much as seven days earlier and possibly with smaller machinery.

With a well drained soil, the ground is worked up more easily and requires less fuel to do the operations. Also there is less chance of equipment getting stuck in wet areas, causing a loss of time as well as potential damage to the equipment. With a well drained soil a fall tillage operation may be possible, creating more time in the spring for other operatios.

One other advantage of draining sloughs or wetlands is that by increasing the area drained this will lower the fixed costs of machinery per acre. If a 25 acre slough is drained on a 1250 acre farm it will lower fixed costs by 2%. This may not seem like very much, but over a period of years it could make quite a difference.

5.1.6 Improved Crop Quality

The area immediately surrounding a slough or wetland is often affected and produces lower quality crops. This area is usually characterized by green patches and lodging, is susceptible to frost and almost always has weed problems.

> "On the basis of survey information and our own professional judgement, the area impacted would be about 3 times the size of the slough area". Marv Anderson and Associates, 1984.

With the lower quality grain produced in that area, there is often a lower crop grade.

The later in the year that a crop is planted, the lower the test weight of the grain and usually the higher the moisture content. When either or both of these conditions occur dockage charges result at the elevator. Also, there is an added drying cost to reduce the moisture content of grain enough to store it.

5.2 Costs

5.2.1 Loss of Moisture

Many farmers oppose drainage because they feel that by putting in a drainage system, they will dry out the land. This is a fallacy as far as mineral soils are concerned. There are three types of water found in the soil:

(i) Hygroscopic water - a thin layer of water which is held so tightly by the soil particles, that it can only be removed by heat drying the soil.

(ii) Capillary water - water in the form of varying thicknesses of films around soil particles. This is the water which is used by the plants. It is held by cohesive forces against gravitational pull. Capillary water is replaced by rainfall or by a rise in the water table.

(iii) Gravitational water - is the water which has filled up the pore spaces in the soil and can be removed by the force of gravity.

When a drainage system is installed properly, its purpose is to remove the gravitational water in the soil. The capillary water and the hygroscopic water remain in the soil. What a drainage system does is remove only the excess water from the soil. There is no danger of overdrying a mineral soil.

With organic soils, overdraining may cause the soils to dry out, allowing rapid oxidation to occur, and the soil may be difficult to rewet. Professional advice should be obtained before draining organic soils.

5.2.2 Waterfowl and Wildlife

By draining sloughs or wetland, waterfowl habitat may be disrupted. In many cases the drainage water is consolidated with other wetlands or ponds, to create a larger area for the waterfowl to occupy. For wildlife such as beavers or muskrats, the problem may not be solved as easily. The wildlife must relocate to areas where they can find permanent habitat. This may cause over-crowding in some areas which may result in a loss of wildlife. The loss of waterfowl and wildlife for recreation and trapping should be charged as a cost against the drainage project.

6. SUMMARY AND CONCLUSIONS

This study used a simple computer model to determine the benefits of drainage in Alberta and to determine the conditions under which sub-surface and surface drainage of sloughs would be economically feasible. Benefits in the form of increased yields and increased efficiency of field operations were quantified and tested against the cost of drainage installation. Discounting was employed to express all cost and benefit streams in present value terms. Non-quantifiable benefits and costs were also discussed.

Drainage was evaluated under irrigated and dryland conditions, with and without salinity problems. Analysis was based on five agroclimatic regions south of Red Deer and three major soil zones for the rest of the province. Differences in soil types were not considered in the development of the saline reclamation equation.

Three initial Ec levels were examined for saline conditions. Four different water application practices were evaluated for the reclamation of irrigated saline areas and three levels of precipitation for dryland saline areas. For all saline conditions, the situations with and without a crop prior to drainage were compared. Where excess water was the problem and salinity minimal, the impact of the frequency with which a crop was produced prior to drainage was tested at four levels.

Under irrigated saline conditions sub-surface drainage was shown to be economically feasible with high water applications and Ec levels of 10 and 15 in all agroclimatic regions. At an Ec level of 20, with no previous crop and high water application rates sub-surface drainage costs would be covered in all regions except C and D. With non-saline conditions sub-surface and surface drainage of irrigated areas was shown to be economically feasible in all regions.

Under dryland saline conditions the expected benefits of sub-surface drainage were not sufficient to cover drainage costs under any of the base conditions examined. With non-saline dryland conditions the feasibility of sub-surface drainage was largely dependent on the frequency with which a crop would be produced without drainage. With 0% to 20% chance of a crop, sub-surface drainage paid in all regions except the Peace (Luvisols). Surface drainage would be feasible under all non-saline dryland conditions, whatever the frequency of cropping before drainage.

Sensitivity analysis showed that sub-surface drainage costs would not be recovered in 5 years (the initial analysis used 10 years for cost recovery). One exception was for non-saline irrigated areas with no chance of a crop being produced without drainage. Extending the project repayment period to 20 and 30 years made sub-surface drainage for irrigated saline conditions feasible in all cases. For dryland saline conditions it became feasible with the highest precipitation level of 35 cm and in some cases 25 cm. Only two cases were feasible with 15 cm.

Where production costs were increased by the inclusion of fixed costs (not included in the original analysis) the feasibility situation changed markedly. Where there was a previous crop the inclusion of fixed costs had no impact on drainage feasibility. Where there was no previous crop fewer cases proved to be economically justifiable. This implied that although the benefits of sub-surface drainage were large enough to cover drainage costs in many instances, they could not cover both existing fixed costs as well as drainage costs.

In conclusion, the results have shown that sub-surface drainage of irrigated saline areas is economically justifiable under most conditions. However, under dryland conditions sub-surface drainage is not justified except over the very long term and with relatively high precipitation levels. Both sub-surface and surface drainage were shown to be economically feasible for non-saline conditions except for specific cases.

Some of the key factors which affect the feasibility of drainage are the initial level of salinity; the level of water applied through irrigation or precipitation to effect leaching; the frequency of crop being produced prior to drainage; production costs and project life.

APPENDIX I

BASIC INFORMATION REQUIRED

```
List of equipment for this situation
----------------------------------------------------------------------------

Number of operations            8
----------------------------------------------------------------------------

operation      num    width    speed hour. charge        # HEAD.        1
                      (ft)  (ft/mn) ($/hour)
----------------------------------------------------------------------------

Cultivate       1       35      484    44.16                 2          1
Harrow          2       35      484    45.52                 2          1
Fertilize       3       68      528    51.68                 2          1
Seed            4       38      484    47.54                 2          1
Spray           5       42     1056    20.32                 2          1
Swathing        6       24      440    27.32                 2          1
Combine         7       24      264    47.55                 2          1
Culitvate       8       35      484    44.16                 2          1
Culitvate       9       35      484    44.16                 2          1
Culitvate      10       35      484    44.16                 2          1
Culitvate      11       35      484    44.16                 2          1
Culitvate      12       35      484    44.16                 2          0
Culitvate      13       35      484    44.16                 2          0
Cultivate      14       35      484    44.16                 2          0
----------------------------------------------------------------------------

obstacle situation
----------------------------------------------------------------------------

situation Area ce  Area co  Area fe   Num ca  Num co  Num fe
          (acres) (acres)  (acres)      #       #       #
----------------------------------------------------------------------------

      1      25       0        0        1       1       1
      2       0       0        0        1       1       1
----------------------------------------------------------------------------

yield information
----------------------------------------------------------------------------------------

crop              DRYLAND ZONE 2
             yield           prod cost                                  price crop mix
----------------------------------------------------------------------------------------

wheat          29              54.46                                    4.38     0.6
barley       43.9              55.41                                     2.8     0.3
alfalfa      1.17              25.74                                   74.25     0.1
Summerfal       0               5.63
----------------------------------------------------------------------------------------

         initial EC level            1
         Co water application first five years                15
         Co water application y 6 to 10                       15
         Co water application rest of project                 15
         Proportion of time you get a crop in this are       0.2
         Proportion of time you summerfallow               0.333

Slough coefficient
----------------------------------------------------------------------------

situation   Oce       Of        Orc    Area tot
       1 1177.520        0 5599.248       25
       2        0        0        0        0
```

ESTIMATION OF EFFICIENCY GAIN, YEARLY Ec LEVELS AND RELATED YILEDS

Time and cost for operation

operation	T.Time 1	T.Time 2	H.Time 1	H.Time 2	% Eff.	cost
1	431.54	481.24	3.20	3.01	0.94	0.14
2	431.54	481.24	3.20	3.01	0.94	0.14
3	225.71	239.61	1.67	1.50	0.90	0.15
4	401.40	445.51	2.97	2.78	0.94	0.15
5	168.62	186.00	1.25	1.16	0.93	0.03
6	667.22	757.53	4.94	4.73	0.96	0.09
7	1112.03	1262.56	8.24	7.89	0.96	0.27
8	431.54	481.24	3.20	3.01	0.94	0.14
9	431.54	481.24	3.20	3.01	0.94	0.14
10	431.54	481.24	3.20	3.01	0.94	0.14
11	431.54	481.24	3.20	3.01	0.94	0.14
12	431.54	481.24	3.20	3.01	0.94	0.14
13	431.54	481.24	3.20	3.01	0.94	0.14
14	431.54	481.24	3.20	3.01	0.94	0.14
totals	4732.689	5297.602	35.05696	33.11001	1.053802	1.396429

total cost difference is 150.9855

summerfallow cost dif. 112.5973 mean cost difference 138.2022

year	Ec	yieldws	yieldbs	yieldas	yieldwns	yieldbns	yieldans
		bu/ac	bu/ac	tons/ac	bu/ac	bu/ac	tons/ac
1	0.953562	0	0	0	24.65	37.315	0.9945
2	0.909282	0	0	0	26.1	39.51	1.053
3	0.867057	0	0	0	27.55	41.705	1.1115
4	0.826793	0	0	0	29	43.9	1.17
5	0.788399	0	0	0	29	43.9	1.17
6	0.751788	0	0	0	29	43.9	1.17
7	0.716877	0	0	0	29	43.9	1.17
8	0.683587	0	0	0	29	43.9	1.17
9	0.651844	0	0	0	29	43.9	1.17
10	0.621574	0	0	0	29	43.9	1.17
11	0.592710	0	0	0	29	43.9	1.17
12	0.565186	0	0	0	29	43.9	1.17
13	0.538940	0	0	0	29	43.9	1.17
14	0.513913	0	0	0	29	43.9	1.17
15	0.490048	0	0	0	29	43.9	1.17
16	0.467292	0	0	0	29	43.9	1.17
17	0.445592	0	0	0	29	43.9	1.17
18	0.424900	0	0	0	29	43.9	1.17
19	0.405169	0	0	0	29	43.9	1.17
20	0.386354	0	0	0	29	43.9	1.17
21	0.368413	0	0	0	29	43.9	1.17
22	0.351305	0	0	0	29	43.9	1.17
23	0.334991	0	0	0	29	43.9	1.17
24	0.319435	0	0	0	29	43.9	1.17
25	0.304601	0	0	0	29	43.9	1.17
26	0.290456	0	0	0	29	43.9	1.17
27	0.276968	0	0	0	29	43.9	1.17
28	0.264107	0	0	0	29	43.9	1.17
29	0.251842	0	0	0	29	43.9	1.17
30	0.240147	0	0	0	29	43.9	1.17

ESTIMATION OF BENEFIT AND COST STREAMS

year	ouput ben	pump C	Xwater C	Eff Gain	prod cost	net gain	dif [illegible]
	$/ac	$/ac	$/ac	$/ac	$/ac	$/ac	$/ac
1	110.90	0.00	0.00	5.53	37.14	79.29	63.43
2	117.43	0.00	0.00	5.53	37.14	85.81	69.95
3	123.95	0.00	0.00	5.53	37.14	92.34	76.48
4	130.48	0.00	0.00	5.53	37.14	98.86	83.00
5	130.48	0.00	0.00	5.53	37.14	98.86	83.00
6	130.48	0.00	0.00	5.53	37.14	98.86	83.00
7	130.48	0.00	0.00	5.53	37.14	98.86	83.00
8	130.48	0.00	0.00	5.53	37.14	98.86	83.00
9	130.48	0.00	0.00	5.53	37.14	98.86	83.00
10	130.48	0.00	0.00	5.53	37.14	98.86	83.00
11	130.48	0.00	0.00	5.53	37.14	98.86	83.00
12	130.48	0.00	0.00	5.53	37.14	98.86	83.00
13	130.48	0.00	0.00	5.53	37.14	98.86	83.00
14	130.48	0.00	0.00	5.53	37.14	98.86	83.00
15	130.48	0.00	0.00	5.53	37.14	98.86	83.00
16	130.48	0.00	0.00	5.53	37.14	98.86	83.00
17	130.48	0.00	0.00	5.53	37.14	98.86	83.00
18	130.48	0.00	0.00	5.53	37.14	98.86	83.00
19	130.48	0.00	0.00	5.53	37.14	98.86	83.00
20	130.48	0.00	0.00	5.53	37.14	98.86	83.00
21	130.48	0.00	0.00	5.53	37.14	98.86	83.00
22	130.48	0.00	0.00	5.53	37.14	98.86	83.00
23	130.48	0.00	0.00	5.53	37.14	98.86	83.00
24	130.48	0.00	0.00	5.53	37.14	98.86	83.00
25	130.48	0.00	0.00	5.53	37.14	98.86	83.00
26	130.48	0.00	0.00	5.53	37.14	98.86	83.00
27	130.48	0.00	0.00	5.53	37.14	98.86	83.00
28	130.48	0.00	0.00	5.53	37.14	98.86	83.00
29	130.48	0.00	0.00	5.53	37.14	98.86	83.00
30	130.48	0.00	0.00	5.53	37.14	98.86	83.00

SUMMARY AND NPV MATRIXES

```
============================================================
ECONOMIC AND PHYSICAL ANALYSIS: SUMMARY
============================================================
        initial EC level
        Cm water application first five years           15
        Cm water application y 6 to 10                  15
        Cm water application rest of project            15
        Proportion of time you get a crop in this are    0.2
        Proportion of time you summerfallow            0.333


        no previous crops

            life                 rate
               y                   %
                   0.035     0.05     0.07      0.1
               5  409.38   391.90   370.33   341.28
              10  785.20   727.26   659.34   573.97
              20 1368.06  1195.90  1012.31   808.17
              30 1781.26  1483.61  1191.74   898.46


        existing crop

            life                 rate
               y                   %
                   0.035     0.05     0.07      0.1
               5  337.78   323.25   305.31   281.17
              10  653.32   604.81   547.96   476.53
              20 1142.69   998.26   844.31   673.17
              30 1489.60  1239.83   994.96   748.93
```

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Bibliography

Anderson Marv. and Associates Ltd., Farming for the Future, Research Project No. 82-0074, 1984.

Andruchow, Lloyd J. Farm Machinery Costs, Alberta Agriculture, Economic Services Division, Production and Resource Economics Branch, Agdex 825-12, 1982.

Baldwin C.S., J.F. Davis, C.E. Broadwell 1965, An analysis of Product Practices on Sugar Beets Farms, 1961-1963, Quarterly Bull. Mich. State University 48:(1) 36-63.

Desjardins, Ronald A. Drainage Section of the Land Improvement Questionnaire Alberta Agriculture, Economic Services Division, Production and Resource Economics Branch, 1983.

Desjardins, Ronald A. The Impact of Obstacles on Farm Operations, Alberta Agriculture, Economic Services Division, Production and Resource Economics Branch, 1983.

Dooley, A. ALBS, Irrigation Expansion: Existing Farm Profile and Economic Component (Sections 5 and 6), 1984.

Irwin, R.W., On Farm Drainage Benefits, University of Guelph.

Kohnke, H. Soil Physics. McGraw - Hill Book Co., N.Y. 1968.

McLelland, Murry, B., Barley Production in Albert Alberta Agriculture, Agdex 114/20-I

Rapp E., L.P. Apedaile, and R. Desjardins (1983). Slough and Wetland Problems in East Central Alberta. Canadian Journal of Agricultural Engineering, Vol. 25, No. 1. summer 1983.

Rousseau, Alain. A Study of Costs and Benefits of On-Farm Surface Drainage in North-Central Alberta, Alberta Agriculture, Economic Services Division, Production and Resource Economics Branch, 1983.

Singh, R.H., J.S.Howden, G.T. Somers, F.Pitura, L.R.Rigaux, Does Farm Drainage Pay?, Manitoba Department of Agriculture, 1973.

Stochinsky S. The Economics of Agricultural Drainage: Irrigated Saline Soils in Southern Alberta, Alberta Agriculture, Economic Services Division, Production and Resource Economics Branch, 1984.

Vander Pluym, H.S.A. Paterson, B., and Holm, H.M. (1981). "Degradation by Salinization". In Agricultural Land: Our Disappearing Heritage - A Symposium. Proceedings of the 18th Annual Alberta Soil Science Workshop.

Van Schaik J.C. and Milne, R.A. (1962); Reclamation of a Saline Sodic Soil with Shallow Till Drainage. Canadian Journal of soil science, 42, 43-48.

THE MODIFICATION OF ARTESIAN AQUIFERS TO ENHANCE AGRICULTURAL DRAINAGE SYSTEMS

November, 1984
Winnipeg, Manitoba

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ABSTRACT

THE MODIFICATION OF ARTESIAN AQUIFERS TO ENHANCE AGRICULTURAL DRAINAGE SYSTEMS

Modifying the topographic expression of watershed units to manage surface runoff is a long standing practice to enhance the use of land for agricultural purposes. Modifying the subsurface expression of watershed units to manage groundwater flow is a relatively new practice in Manitoba to enhance the use of land for agricultural purposes. Modifications to an artesian aquifer in the Netley Creek Watershed were undertaken as part of the reconstruction project completed on the Ross Creek Drain in 1982. These aquifer modifications have proved successful in enhancing the use of land in the watershed for agricultural purposes.

L. Gray, P. Eng.
July, 1984.

CONTENTS

Introduction

Watershed Description

Problems Associated with Artesian Aquifers

Conditions Before Aquifer Modification

Conditions After Aquifer Modification

Impact of Aquifer Modification

Conclusions

INTRODUCTION

In Manitoba groundwater discharge can interfere with the effectiveness of agricultural drainage systems by promoting the growth of dense vegetation during the summer and the buildup of ice during the winter. Both conditions cause a reduction in the flow capacity of drainage channels. A common source of groundwater discharge in the Lower Red River Valley is the carbonate rock aquifer confined by a mantle of glacial deposits consisting mainly of clay and till. The location of flowing wells as shown in Figure 1 indicates areas of artesian discharge. A program to minimize the adverse effects of groundwater discharge was implemented in Watershed No. 30, also shown in Figure 1, during a period from 1977 to 1982.

Most of the groundwater activities associated with this program were completed by Mr. J. Korol, P. Eng., who is no longer with the Department. In preparing this paper I have been assisted by Mr. J. Petsnik, P. Eng., Watershed Hydrogeologist and Mr. J. Mamott, Drafting Technician with the Department of Natural Resources. Their contributions are gratefully acknowledged.

WATERSHED DESCRIPTION

Watershed No. 30 is a subunit of the Red River Basin containing 782 km^2 of land that drains eastward from a divide at elevation 274 m through Netley Creek into the Red River at elevation 217 m. The upper part of the watershed is characterized by a gently sloping till plain and the lower part is characterized by gently sloping lake clay plain. The transition between the upper and lower parts of the Watershed is characterized by a more severe slope where the elevation change is 25 m in 5 km. The gentle slope of the plains in the upper and lower parts of the watershed did not support the development of well defined natural water courses in much of the watershed. Limited natural water course development has taken place in the transition zone and near the outlet of the watershed (these features are shown on the original township plans prepared by the Dominion Land Survey between 1874 and 1922).

This lack of natural water course development has lead to the development of a fairly extensive man-made drainage network shown in Figure 2 (this network reflects the land subdivision pattern established by the Dominion Land Survey).

The subsurface structure of the watershed is depicted in the hydrogeologic cross-section (Figure 3). The stratigraphic framework consists of a carbonate rock unit overlain by glacial deposits consisting of till and associated gravel and clay. The saturated portion of the carbonate rock and the gravel form the main aquifer in the watershed. The position of the water level associated with this aquifer indicates water table conditions in the upper part of the watershed and artesian conditions in the lower part. Discharge from the artesian aquifer was documented on the Dominion Land Survey document published in 1874 which identifies the location of two springs on the plan of township 15, range 2, east of the first meridian. These early survey documents also identify an area immediately downstream from the location of the springs as the "Great Marsh". This feature resulted from the combined effects of poor natural drainage and year-round discharge from the artesian aquifer. Land drainage activities including modification of the artesian aquifer have converted the "Great Marsh" into the most productive agricultural land in the watershed.

PROBLEMS ASSOCIATED WITH ARTESIAN AQUIFERS

Discharge from artesian aquifers can seriously interfere with the operation of man-made land drainage systems by reducing the flow capacity of channels and crossings. Flow capacity is reduced by dense vegetation in the summer and ice buildup in the winter. The conditions under which groundwater from artesian aquifers can enter land drainage systems are shown in Figure 4. Flowing wells are man-made water supply structures that provide an outlet for water from artesian aquifer. Blowouts result from earth excavation projects where part of the confining layer above the aquifer is removed allowing the pressure in the aquifer to exceed the pressure of the confining layer. Springs occur naturally in areas where the pressure of the confining layer is less than the pressure in the aquifer. All three conditions are common in watershed units in the lower Red River Valley. This situation stems from the fact that much of the agricultural land development in Manitoba took place at a time when the knowledge and understanding of groundwater systems was very limited. Todays knowledge and understanding of groundwater systems in the province allows us to resolve the problems associated with previously developed agricultural land and to avoid similar problems in the new land developments. This paper deals mainly with the method used to resolve the problems in Watershed No. 30 associated with Ross Creek Drain.

CONDITIONS BEFORE AQUIFER MODIFICATION

Several points of discharge from the artesian aquifer were identified from a field survey of the area adjacent to Ross Creek Drain as shown in Figure 5. These included flowing wells, blowouts and springs. Rates of discharge varied from less than 1 L/s to more than 12 L/s. The higher rates of discharge were from a blowout in the road allowance drain south of section 1-16-2E (this point of discharge resulted from a drain cleanout in the 1960's) and a long established discharge feature locally referred to as "Blue Spring" located near the centre of section 8-16-3E (it is likely that this point of discharge resulted from a very early attempt to establish a water supply well). The lower rates of discharge were from wells and springs. The combined rate of groundwater discharge from all sources was in the order of 35 L/s.

The main strategy adopted to manage the water discharged from the artesian aquifer prior to 1977 was to provide an outlet through the drainage network. In some cases this required extending drainage channels through the middle of a section to collect water discharged from springs (section 25-15-2E). The end result of this strategy was groundwater flow on a year-round basis at relatively low rates (less than 1 to greater than 12 L/s) in approximately 20 km of the drainage network. Because of ice build-up in the drainage channels all crossings required timber bridges instead of less expensive metal culverts. In considering reconstruction alternatives for Ross Creek Drain in 1977 the difference in cost between structures that could function with ice conditions and structures that could function without ice conditions was $55,000.00. This capital cost saving along with projected lower drainage maintenance costs provided an incentive to seek a solution to the icing problem.

CONDITIONS AFTER AQUIFER MODIFICATION

In looking for solutions to eliminate the icing problem it was recognized that discharge from flowing wells could be eliminated by direct sealing, discharge from springs could be controlled by ring dykes although this was considered impractical because of the height required above ground (a ring dyke had been employed by a local landowner in section 2-16-2E with marginal success) and discharge from the blowout could be eliminated by raising the channel bottom (this solution as well as channel relocation were not feasible). The solution chosen was to modify the water level (reduce the pressure) in the artesian aquifer in the vicinity of the discharge points. The critical requirement was to reduce the pressure in the aquifer at the location of the blowout to a level where the pressure in the aquifer was slightly less than the pressure of the confining layer.

Conditions associated with the artesian aquifer indicated that the required pressure reduction might be accomplished by locating free-flowing relief wells in the vicinity of the "Blue Spring" (Section 8-16-3E). Test wells in the area ultimately led to the establishment of two permanent free-flowing relief wells that provided the required pressure reduction. The location of these relief wells and the modified distribution of groundwater flow in the drainage network is shown in Figure 6. Water level changes in the artesian aquifer caused by the relief wells were recorded at the observation well also shown in Figure 6.

IMPACT OF AQUIFER MODIFICATION

Aquifer modification was achieved by changing the number, location and flow rates of points of discharge from the artesian aquifer associated with Ross Creek Drain (rates of discharge for the two permanent relief wells were 50 L/s and 20 L/s for a combined total of 70 L/s). The end result of these changes was to establish a new water level regime for the carbonate rock aquifer system. The magnitude of water level change associated with the artesian aquifer is shown in Figure 7. This hydrograph was obtained from the observation well shown in Figure 6.

Apart from achieving the intended purpose of resolving the icing problem associated with the drainage network the change in groundwater levels did affect a number of existing water supply facilities in the local area. To accommodate the water level changes a number of water supply facilities had to be modified. The number, type and cost of water system modifications is shown in Figure 8. Two factors that combined to make the water supply system modifications more difficult than anticipated involved (1) many of the existing water systems were old (some wells had been in operation for 20 years or more) and were designed in such a fashion that there was very little tolerance to accommodate changes in water level and (2) below normal precipitation in the watershed caused groundwater levels to be below normal for much of the two year period following the installation of the relief wells. However, the modifications made to existing water supply facilities not only restored the water supply capacity of individual systems but also resulted in a substantial capital improvement to the local water supply infrastructure.

The elimination of discharge from springs located in farm fields also eliminated the need for maintaining on-farm drainage works such as ring dykes and outlet channels. Ring dykes have been levelled and the associated land restored to crop production in sections 24-15-2E and 2-16-2E. An on-farm outlet channel from a former spring site in the southwest quarter of 25-16-2E has been backfilled removing a significant impediment to field cropping operations. There is also evidence that land use conversion is taking place in the watershed where lands previously restricted to native vegetation or grass production because of excessive wetness related to groundwater discharge are being converted to more productive crops.

The combined discharge from the two relief wells located 340 m apart along the same drain also serves to produce normal under-ice flow conditions in the downstream portion of the watershed during the winter. This is in contrast to the fairly severe icing conditions that resulted from the lower winter flows that existed prior to the aquifer modification.

CONCLUSIONS

The present-day knowledge of groundwater systems in Manitoba can be utilized to effectively modify the water environment of watershed units to enhance the productivity of the land base. In the case of Watershed No. 30, the agricultural capability of the land base was enhanced (the Oak Hammock project completed a few years ago in an adjacent watershed unit served to enhance the wildlife capacity of the land base using similar aquifer modification methods). Aquifer modification is an important tool that can be utilized in conjunction with the development of surface drainage networks to create water environments that enhance the utilization of the land base.

REFERENCES

Dominion Land Survey. 1874. Plan of Township 15, Range 2, East of First Mieridian.

Dominion Land Survey. 1874. Plan of Township 15, Range 3, East of First Meridian.

Department of the Interior. 1922. Plan of Township 16, Range 2, East of the Principal Meridian.

Department of the Interior. 1922. Plan of Township 16, Range 3, East of the Principal Meridian.

ILLUSTRATIONS

FIGURE 1	Location plan of regional setting showing flowing wells.
FIGURE 2	Plan of watershed showing description of drains and project area.
FIGURE 3	Hydrogeologic cross-section of watershed.
FIGURE 4	Artesian Aquifer Problems.
FIGURE 5	Plan of Ross Creek showing points of discharge and sections of drains carrying groundwater before aquifer modification.
FIGURE 6	Plan of Ross Creek showing points of discharge and sections of drains carrying groundwater after aquifer modification.
FIGURE 7	Chart showing water level changes in the aquifer.
FIGURE 8	Chart showing modifications to water supply wells.

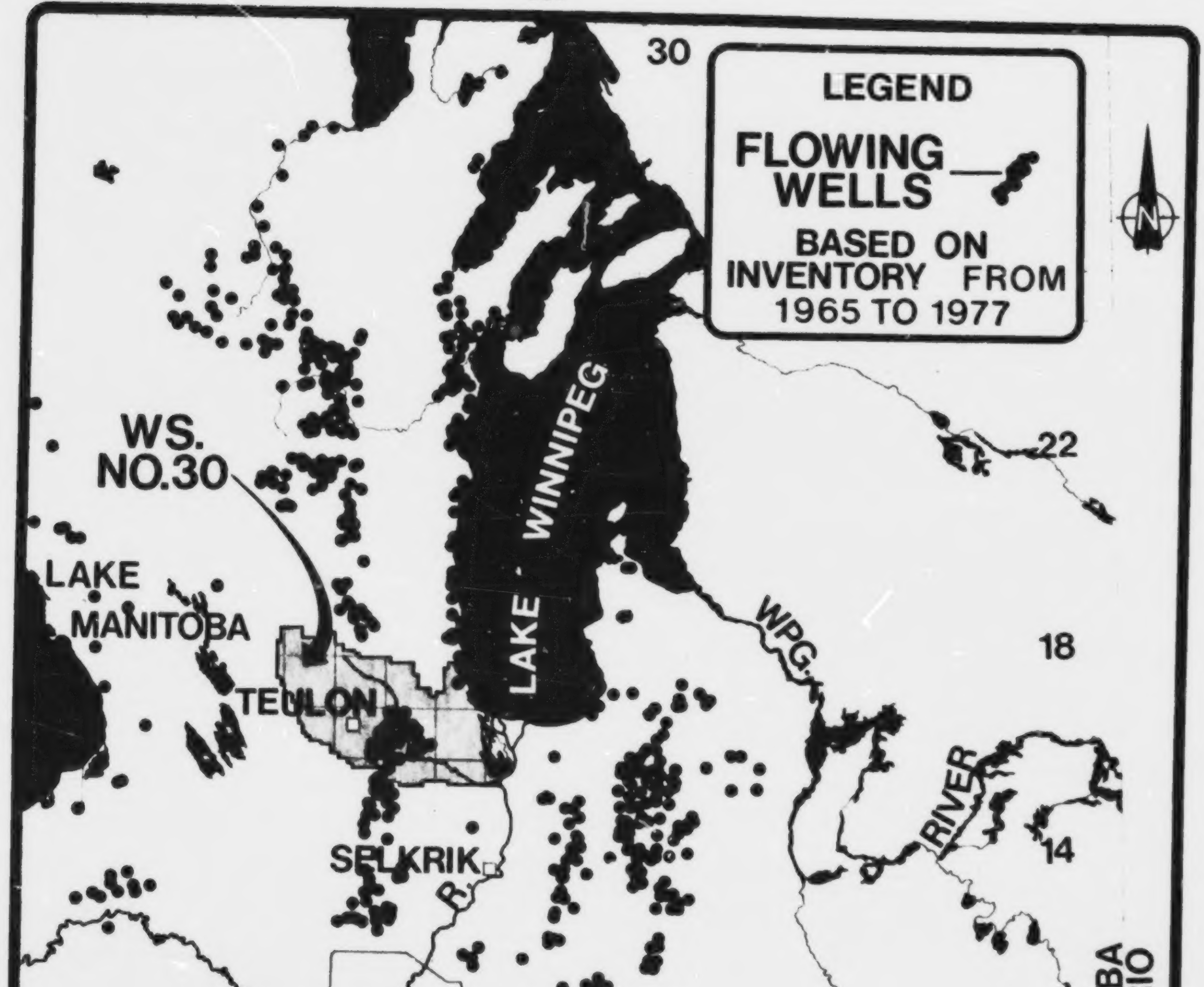

LEGEND
FLOWING WELLS
BASED ON INVENTORY FROM 1965 TO 1977
N
30
WS. NO.30
LAKE MANITOBA
TEULON
LAKE WINNIPEG
WPG. RIVER
22
18
14
10
SELKRIK
R.
WINNIPEG
RED
MANITOBA
ONTARIO
5
1
1
5
9
13
6
17
MORRIS
LAKE OF THE WOODS
1
EMERSON
MANITOBA
MINNESOTA
NORTH DAKOTA

FIGURE 1

LOCATION PLAN

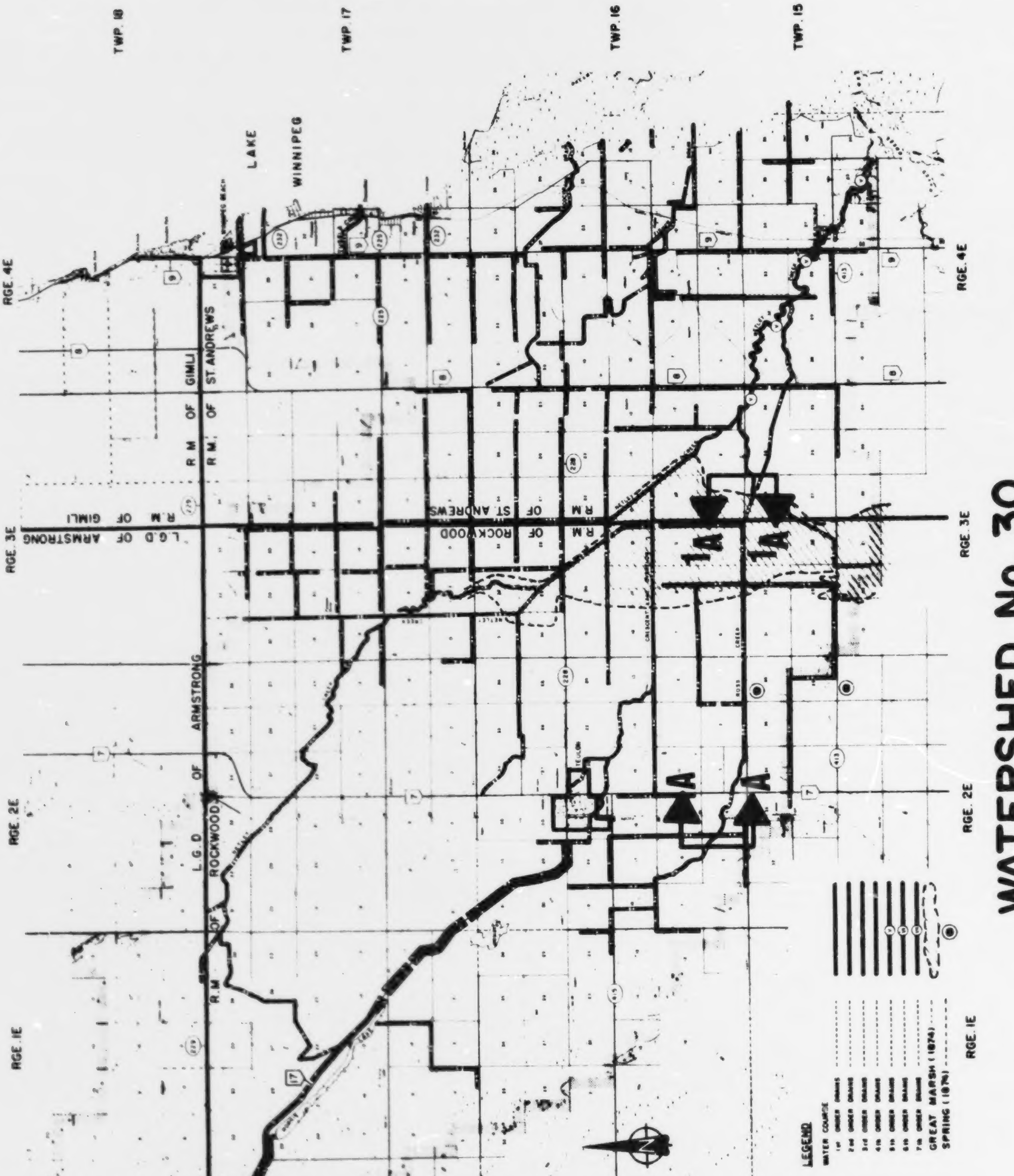
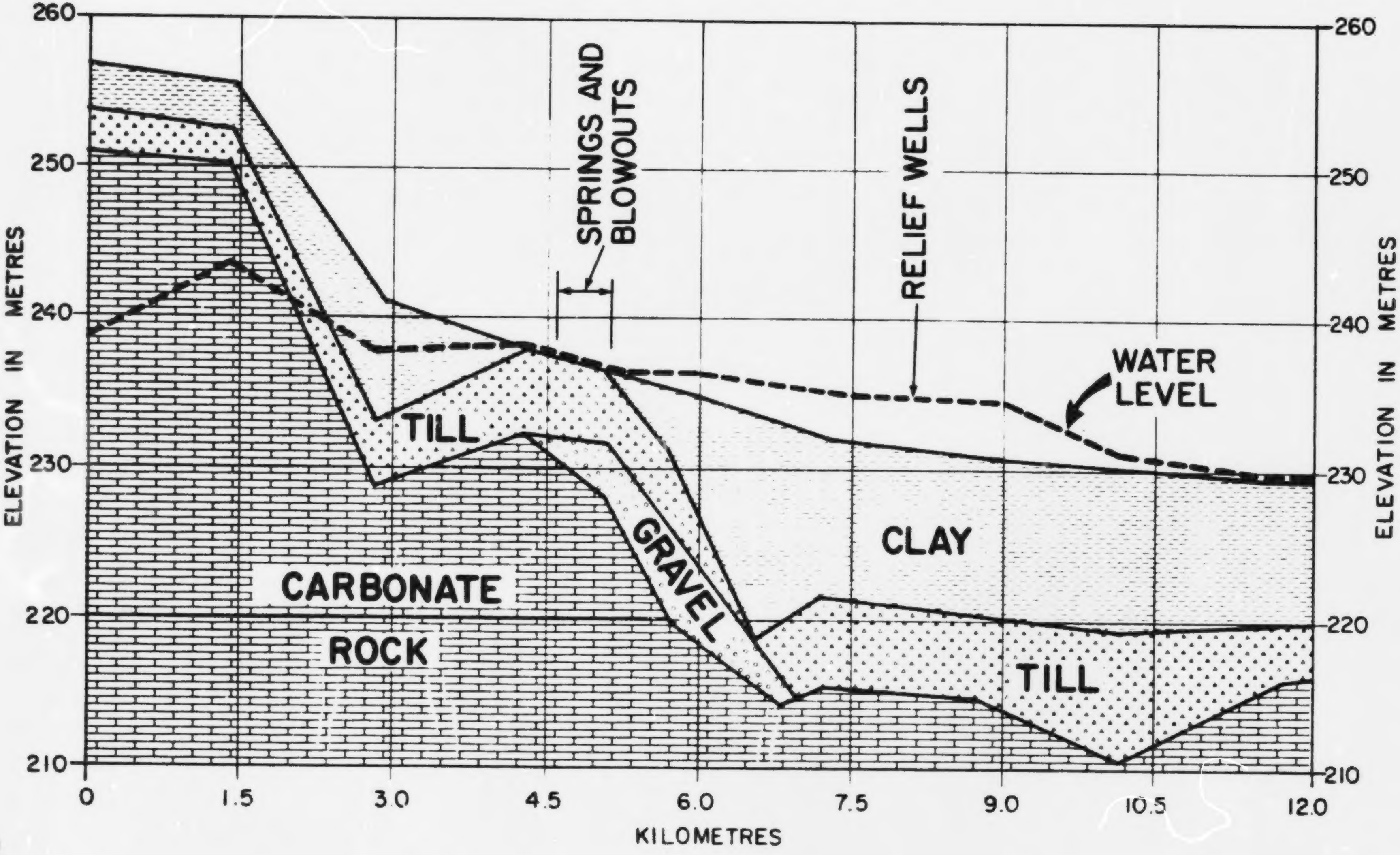
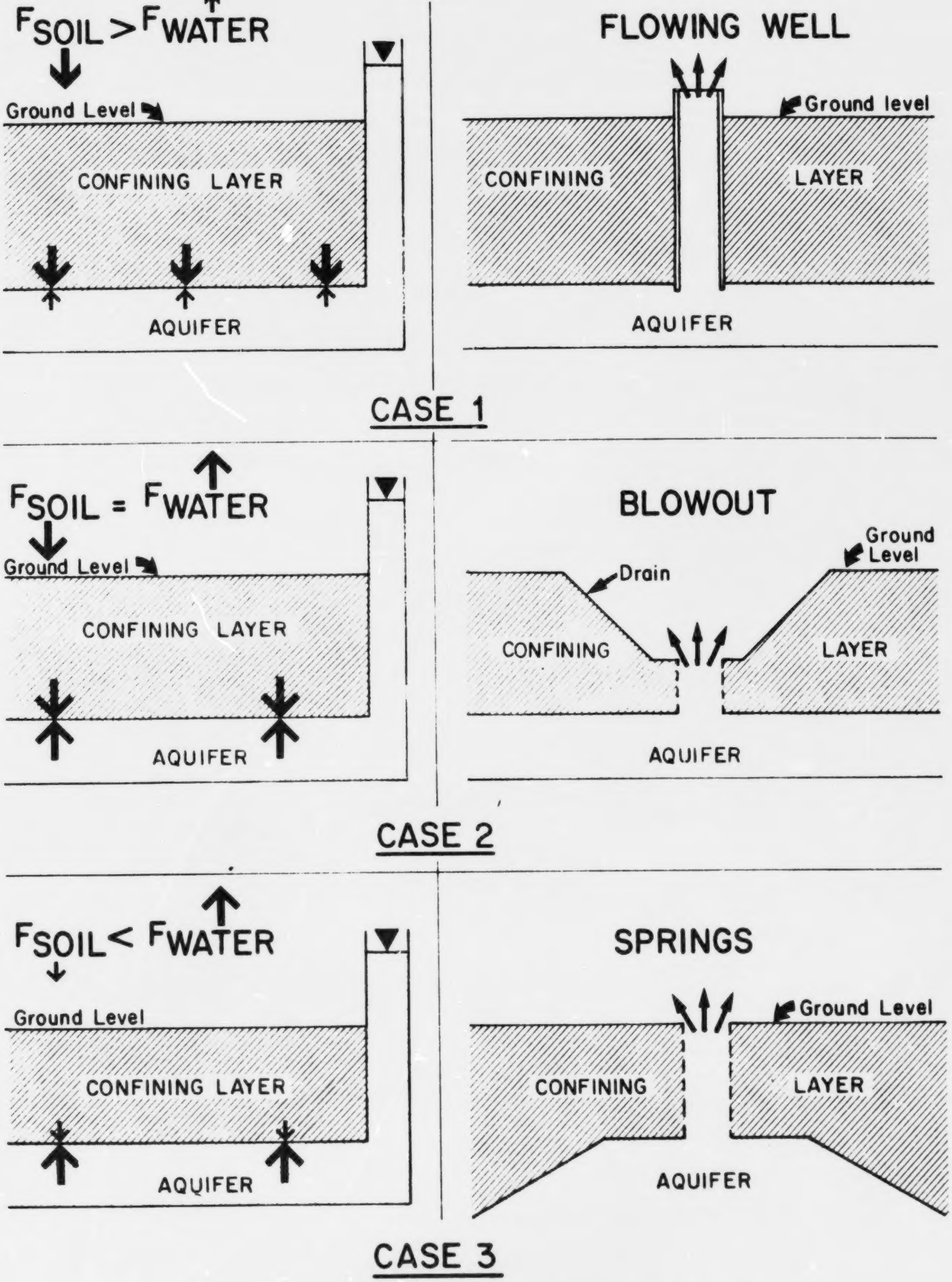

WATERSHED No. 30
LAKE
WINNIPEG
TWP.18
TWP.17
TWP.16
TWP.15
RGE.1W
RGE.1E
RGE.2E
RGE.3E
RGE.4E
R.M. OF GIMLI
R.M. OF ST. ANDREWS
L.G.D. OF ARMSTRONG
R.M. OF ROCKWOOD
L.G.D. OF ROCKWOOD
R.M. OF ARMSTRONG
R.M. OF WOODLANDS
1A
1A
A
A
TEULON
ROSS CREEK
LEGEND
WATER COURSE
1st ORDER DRAINS
2nd ORDER DRAINS
3rd ORDER DRAINS
4th ORDER DRAINS
5th ORDER DRAINS
6th ORDER DRAINS
7th ORDER DRAINS
GREAT MARSH (1874)
SPRING (1874)

FIGURE 2



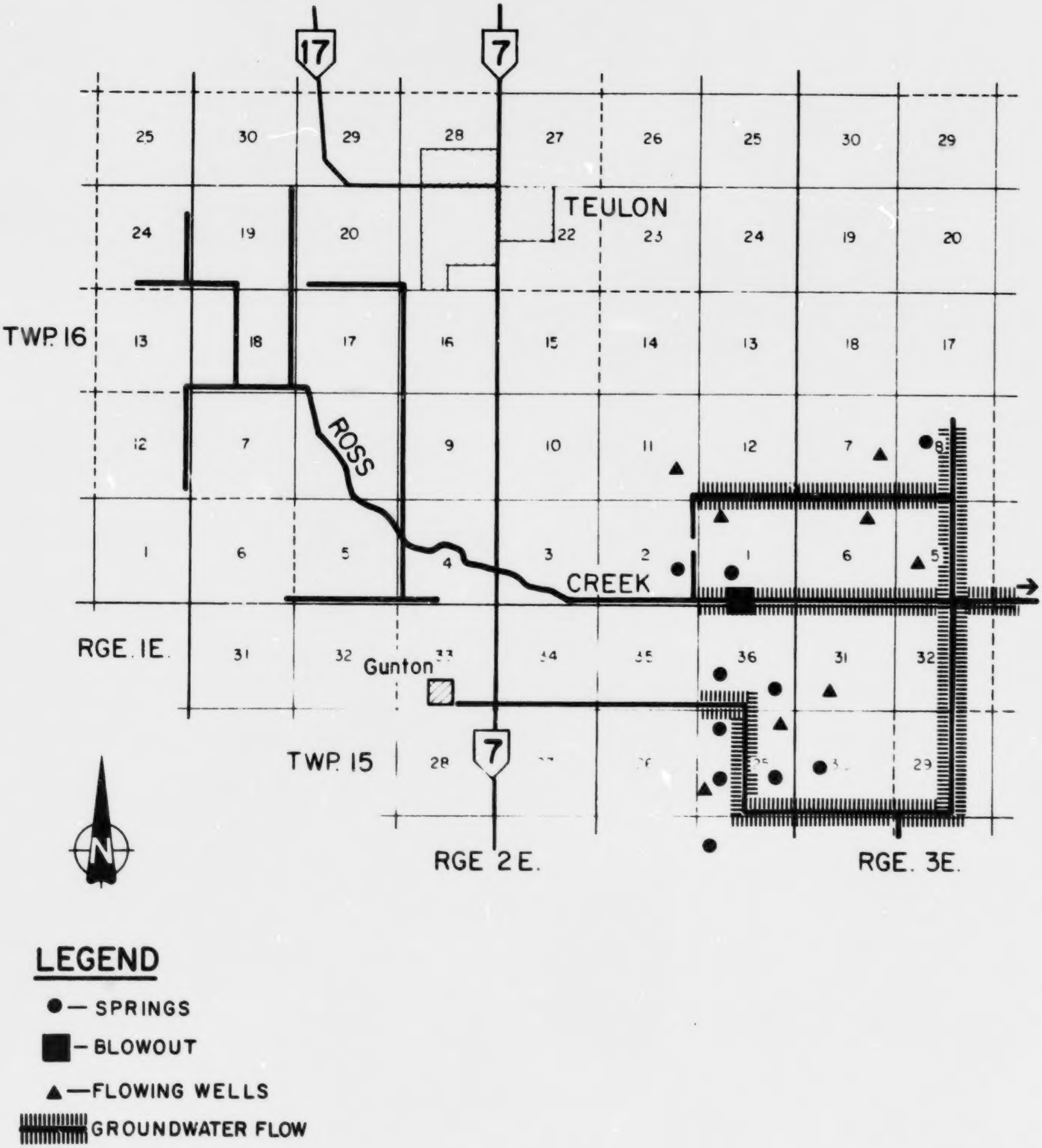
HYDROGEOLOGIC CROSS-SECTION A -^{1}A

FIGURE 3


$F_{SOIL} > F_{WATER}$
Ground Level
CONFINING LAYER
AQUIFER
FLOWING WELL
Ground level
CONFINING
LAYER
AQUIFER
CASE 1
$F_{SOIL} = F_{WATER}$
Ground Level
CONFINING LAYER
AQUIFER
BLOWOUT
Ground Level
Drain
CONFINING
LAYER
AQUIFER
CASE 2
$F_{SOIL} < F_{WATER}$
Ground Level
CONFINING LAYER
AQUIFER
SPRINGS
Ground Level
CONFINING
LAYER
AQUIFER
CASE 3

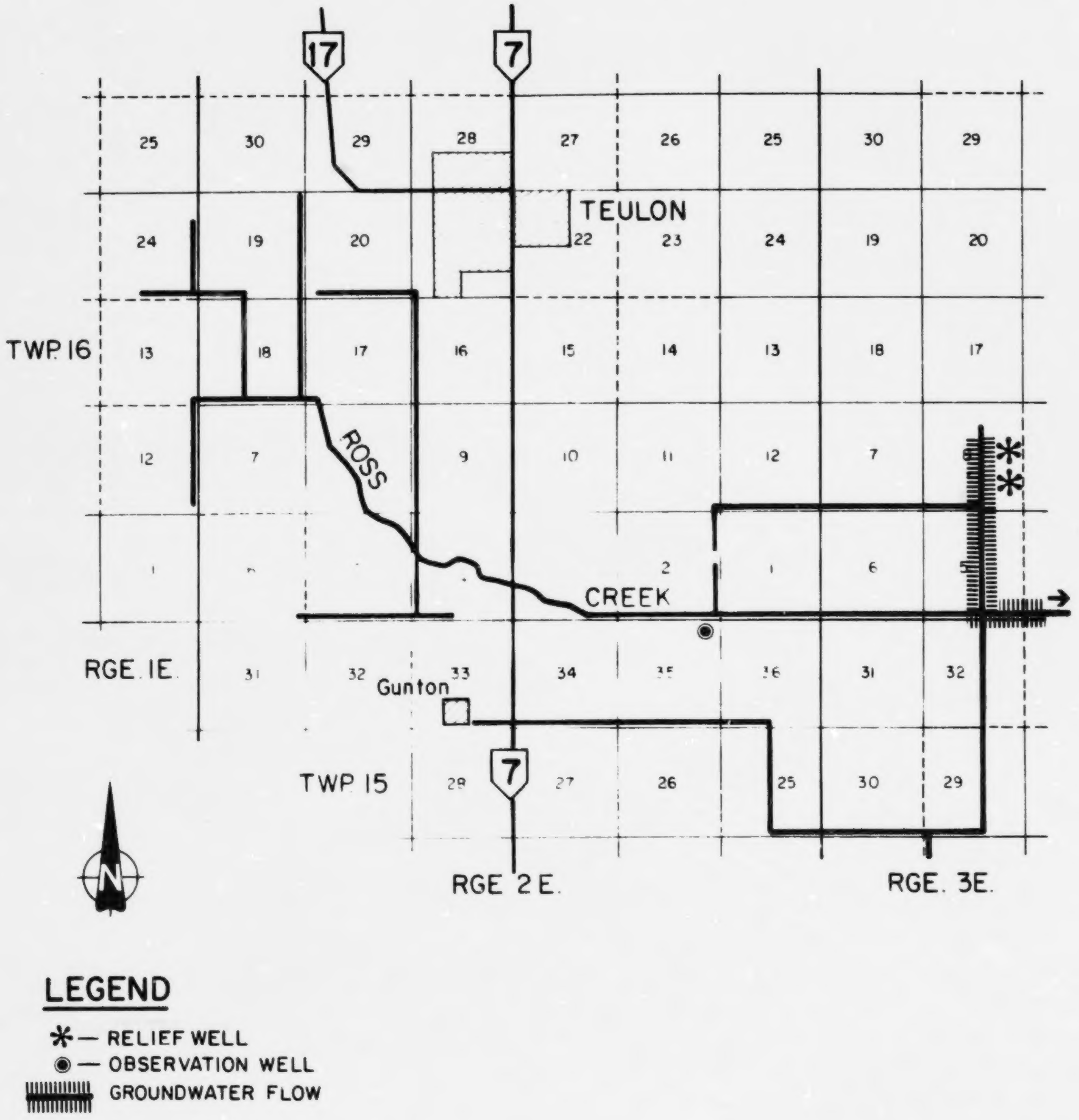
ARTESIAN AQUIFER PROBLEMS

FIGURE 4


17
7
25 30 29 28 27 26 25 30 29
TEULON
24 19 20 22 23 24 19 20
TWP. 16
13 18 17 16 15 14 13 18 17
12 7 9 10 11 12 7 8
ROSS
1 6 5 4 3 2 1 6 5
CREEK
RGE. 1E.
31 32 33 34 35 36 31 32
Gunton
TWP. 15
28 7 29
RGE 2E.
RGE. 3E.
N
LEGEND
● — SPRINGS
■ — BLOWOUT
▲ — FLOWING WELLS
GROUNDWATER FLOW

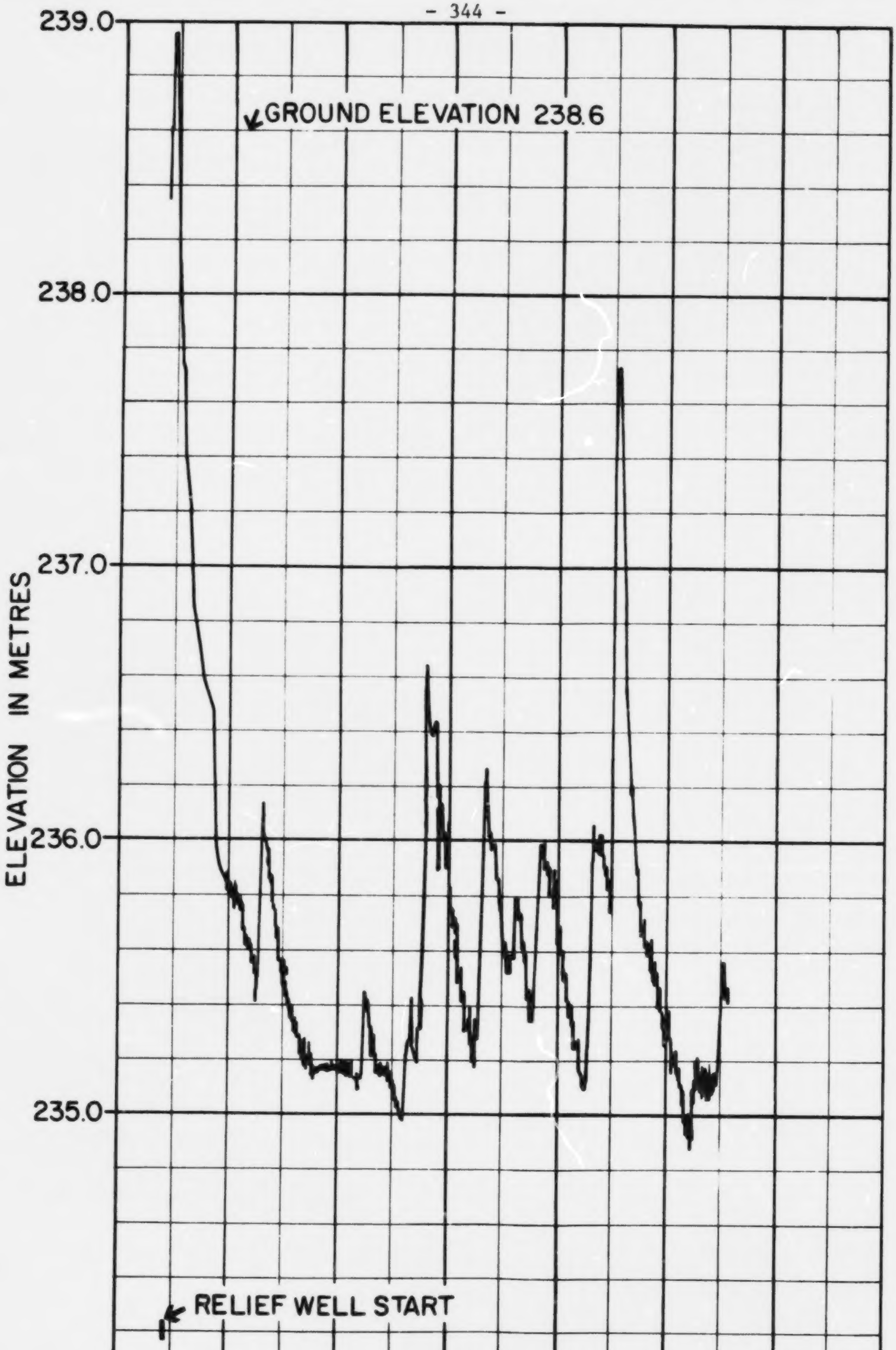
BEFORE AQUIFER MODIFICATION

FIGURE 5


17
7
TEULON
TWP. 16
ROSS
CREEK
RGE. 1E.
Gunton
TWP. 15
RGE. 2E.
RGE. 3E.
N
LEGEND
✱ — RELIEF WELL
◉ — OBSERVATION WELL
GROUNDWATER FLOW

AFTER AQUIFER MODIFICATION

FIGURE 6



WATER LEVEL CHANGE

FIGURE 7

ITEM	NUMBER	COST
NO MODIFICATION	28	-
PUMP ADJUSTMENT	5	-
PUMP MODIFICATION	5	235
PUMP REPLACEMENT	1	470
WELL MODIFICATION	8	4,064
WELL REPLACEMENT	2	1,260
WELL AND PUMP REPLACEMENT	1	4,000
TOTAL	50	10,029

WATER SUPPLY MODIFICATIONS

FIGURE 8

DRAINAGE DESIGN CONSIDERATIONS FOR FISH PASSAGE

C. Katopodis[1]

SYNOPSIS

Hydraulic structures which supply water to or drain water from agricultural lands frequently interfere with upstream or downstream fish migrations. The design of a hydraulic structure requires special attention whenever fish passage is contemplated. Both economy and fish habitat conservation are achieved at the design stage. Corrective action after structures are in place is habitually much more costly. The designer has several options that can facilitate fish migrations and this paper describes most of them. They include fishways, fish locks, fish lifts, and fish screens. Basic design considerations for these structures are reviewed and areas for further study are identified.

RESUME

Les installations hydrauliques servant à l'irrigation ou au drainage des terres agricoles nuisent souvent au passage en aval ou en amont des poissons migratoires. On doit porter une attention particulière à la conception de ces installations lorsqu'on doit tenir compte du passage de poissons. En effet, c'est lors de la conception même que l'on peut économiser et assurer la conservation de l'habitat des poissons. Les modifications qu'il faut apporter aux installations en place sont habituellement beaucoup plus coûteuses. Ce rapport décrit plusieurs possibilités pour faciliter la migration des poissons, notamment les échelles, écluses, ascenseurs et claies à poissons. On procède à une nouvelle étude des éléments dont on doit tenir compte dans la conception de telles installations, et on cerne les domaines à étudier davantage.

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INTRODUCTION

The streams and rivers that supply water for or receive water from agricultural lands provide habitat for valuable fish stocks which are a significant source of food and recreation. Dams, spillways, drop structures, control structures, weirs, canals, intakes, culverts, all are hydraulic structures that are built to collect and transport water to or drain water from agricultural lands. Hydraulic structures affect human, fish, and wildlife inhabitants and environmental considerations are an integral part of the design and construction of these structures.

Interference with fish migrations is a frequent concern in fish-bearing waters. Fish migrate for spawning, rearing, feeding, overwintering. Adult fish usually migrate upstream to their spawning grounds and may have to pass over or through hydraulic structures en route. Both adult and young fish moving downstream may have to negotiate the same structures and avoid entrapment. A number of hydraulic structures have been devised to accommodate fish migrations and prevent entrapment. These structures include fishways, fish locks and fish lifts to assist upstream migrants, and fish screens to prevent downstream migrants from entering hazardous areas. This paper reviews some basic biological and engineering considerations in designing hydraulic structures for fish passage, and identifies areas requiring further investigation.

Fishways help conserve, restore, or develop fish habitats upstream of new (e.g. culvert), old (e.g. dam), or natural (e.g. waterfall) obstructions. Fish habitats form the supporting base of Canada's varied and important fisheries. The concern with fish habitat conservation is analogous to the concern with soil and water conservation in agriculture.

BIOLOGICAL CONSIDERATIONS

LIFE HISTORY

The most important fish species in western and northern Canada are members of the salmonid, percid, hiodontid, or esocid families. The family Salmonidae is divided into three subfamilies: the salmons, trouts and charrs (Salmoninae), the inconnu, whitefishes and ciscoes (Coregoninae), and the graylings (Thymallinae). Walleye, goldeye, and northern pike belong to the families Percidae, Hiodontidae, and Esocidae, respectively (Scott and Crossman 1973).

Each species of fish has a unique life cycle and specific habitat requirements. For most fish, migrations are a momentous part of their life cycle. The main movements in the life cycle of fish are the spawning, feeding and overwintering migrations. In general terms fish migrations conform to the following pattern: young stages proceed from spawning areas to nursery areas; from nursery areas juveniles travel to feeding and overwintering areas; mature and ripening fish move from feeding and overwintering areas back to spawning areas; then they either die (e.g. Pacific salmon) or return to feeding and overwintering areas.

The rate of sexual maturation and time of spawning depend on heredity and environmental factors (e.g. water temperature, photoperiod, etc.), and cannot adjust to prolonged delays. Access to suitable habitat without excessive delay is, therefore, essential to a healthy fishery. Fish passage facilities (i.e. hydraulic structures for fish) are used to provide this access when obstructions are encountered. Investigations and consultation with federal and provincial fisheries agencies are essential for determining the need for fish passage facilities at each site.

The technology which has evolved to pass adult fish over dams or through culverts (fishways, fish locks, fish lifts) and to prevent the entrainment of eggs, larvae and juveniles (fish screens) is extensive. Detailed descriptions of the life cycle of each species of fish provide an understanding of the requirements for each species and is essential for the development of effective fish passage facilities.

FISH BIOMECHANICS

Fish biomechanics form the basis for many of the design criteria for fish passage facilities. The ability of fish to swim against opposing water velocities is a very important aspect in the design of fishways and fish screens. The swimming ability of a particular species, or specific age groups within a species, limits the water velocities that allow fish to migrate upstream over or through hydraulic structures. Swimming performance also limits the approach velocities for fish screens so impingement is avoided. The swimming capabilities of fish are described in terms of three levels of performance or three biokinetic levels. Each reflects the constraints imposed by the length of time fish can maintain the effort and by the biochemical processes through which fish derive the energy for the activity. In order of increasing speed, the three biokinetic levels are termed sustained, prolonged and burst.

Fish can maintain sustained speeds almost indefinitely (usually longer than 200 min) without fatigue; aerobic processes supply the energy. Sustained speeds include activities such as foraging, station holding, schooling, and migrating. Burst speeds are achieved at maximum effort lasting for only 15 s or less; energy is supplied mostly anaerobically. Burst swimming is essential for survival as many species need this high biokinetic level to capture prey, avoid predators or negotiate high velocity areas in streams during migrations. For prolonged speeds the swimming period lasts between 15 s and 200 min and ends in fatigue. Metabolism is either aerobic or anaerobic or both. A special category of prolonged speed, termed the critical speed, is used in laboratory swimming flumes. The critical speed designates the maximum speed fish can maintain for a precise time period. Swimming performance is affected by many factors including fish length, maturity, sex, and condition, as well as, water temperature, dissolved oxygen concentration, and water quality (Hoar and Randall 1978).

OTHER BIOLOGICAL FACTORS

Fish behaviour is critical to the choice and design of fish passage facilities. The designer needs to know whether fish: (a) search for specific flow conditions, (b) enter restricted openings, (c) accept space constraints, (d) prefer submerged or surface orifices, or (e) react to light conditions. Fish have a tendency to assemble in schools and may enter passage facilities in groups rather than individually. In fish schools, both the distance between fish and fish density increase with fish length. This may be a factor in determining facility dimensions (Hildebrand et al. 1980).

Consumption of oxygen by fish depends on species, size, swimming speed, water temperature, and concentration of pollutants. Oxygen consumption is a concern in fish locks, fish lifts and for fish transport in tanks. When fish are crowded, they become extremely agitated and have a higher oxygen consumption rate.

Fish migrating downstream may face injury or death when passing over spillways. Direct physical injury (e.g. abrasion, impact, shearing) or indirect injury (e.g. bubble disease, predation, elevated water temperatures, dewatering and stranding) may occur below a spillway. Although potential for damage exists at dams as low as 7 m (Bell 1984), critical fish conservation problems with downstream passage are uncommon at most spillways of up to about 30 m in height (Ruggles and Murray 1983).

ENGINEERING CONSIDERATIONS

FISHWAYS AT DAMS

Several reviews of the development and design of fishways at dams are available (Bell 1984; Clay 1961; Hildebrand et al. 1980; Katopodis 1981a; Katopodis and Rajaratnam 1983). Katopodis (1981a) summarizes design guides for locating the fish entrance and exit, selecting the type of fishway and its dimensions, sizing resting and counting pools, and spacing trash rack bars. These guides may have to be revised once analysis of swimming speeds, hydraulic model tests and field studies are completed.

In fishways, fish swim up on their own volition. Generally, three basic fishway types are used: the pool and weir, the vertical slot and the Denil. Several variations of each of these three designs exist and Fig. 1, 2 and 3 depict some of the most common. Fig. 4 illustrates operational characteristics for each fishway. Other fishway designs, which have been used very infrequently, include the Borda mouthpiece and the Aeroceanics fishways. These two fishways consist of respectively, a rectangular channel with alternating half-sections of Borda orifices, and an ascending spiral channel with vertical staggered baffles.

Fig. 2 provides some typical dimensions for vertical slot fishways in British Columbia (adapted from Clay 1961). The head drop per pool is commonly 230-300 mm for salmon, and 200 mm or less for most adult freshwater species. Pool dimensions and head drops in pool and weir fishways are usually similar to the ones for vertical slot fishways. Fig. 3 provides dimensions for a "standard" Denil, although fishway height (Y) is not restricted to 690 mm. Several variations in fishway width, baffle spacing and orientation have been used (Katopodis and Rajaratnam 1983). Resting pools are recommended between 7-12 m segments of Denil fishway (Fig. 4).

The hydraulics of Denil fishways were studied extensively. Basic design information such as water velocity profiles and discharge rating curves for Denil fishways are now available (Katopodis and Rajaratnam 1983; Rajaratnam and Katopodis 1984; Katopodis and Rajaratnam 1984). Fig. 3b presents a typical velocity profile along the centerline of a "standard" Denil fishway (Fig. 3a), and Fig. 5 presents the discharge rating curve for this Denil design. Results from three model scales were used. Water velocities in Denil fishways and fish swimming performance can now be matched.

The following list of guides for sizing fishways were compiled from Bell (1984), Clay (1961), Decker (1967), and Hildebrand et al. (1980). Although these guides are intended for salmon, they are useful in developing guidelines for other species.

1. Minimum water depth of 0.6 m to allow sufficient swimming and resting space.
2. Minimum water volume in pools of 5 L/W of water power entering the pool to provide adequate energy dissipation.
3. Minimum pool volume of 13 L/kg of fish to avoid crowding, delays, excessive activity, and fallbacks through the fishway.

Fig. 6 and 7 illustrate fishway locations for dams used in drainage and irrigation projects. Locating the fish entrance so fish can find it easily is most important. Frequently additional water is provided at or near the fish entrance to attract fish. During fish migration this attraction water should approximate 3% of the mean annual stream flow (Hildebrand et al. 1980).

Unit costs for fishways may vary from $25,000 to $70,000 per m of passage height. Operation and maintenance costs for fishways are estimated at 2% to 3% of total unit costs annually (Hildebrand et al. 1980). Unit costs for the Fairford Dam fishway, completed early in 1984, were approximately $50,000 per m of passage height. This was a timber Denil fishway retrofitted to an existing dam in Manitoba. In contrast, unit costs for new Denil fishways in Alberta are less than $10,000 per m of passage height.

FISH LOCKS AND FISH LIFTS

Schematics of fish lock and fish lift systems are shown in Fig. 8 (adapted from Bell 1984). Both the fish lock and the fish lift use a fish collection facility, a V-trap, and a fish crowding device. In the lock, fish are moved into the lock chamber and raised upstream by a cyclical operation similar to that of a navigation lock. In the lift, fish are forced into the water-filled hopper, which is then elevated to the headwater level. Fish are then released above the dam or discharged into a hauling tank for delivery at more distant locations. The fish lift operation does not require the filling and draining of ports, while the fish lock operation does.

Fig. 8 shows typical dimensions for fish locks and lifts (adapted from Bell 1984). The site of the lock chamber is determined using the guide of 13 L/kg of fish (given earlier). This space allows fish to survive for about 16 min in 10°C water saturated with oxygen (Hildebrand et al. 1980). If the crowder is used then the transfer time must be considered also. In this case then, the lock chamber volume is based on 0.8 L/kg/min of transfer time. The fish lift hopper volume is estimated with this guide also.

Although fishways may be selective as to species and sizes of fish, locks and lifts can pass practically all species and sizes. Both fish locks and lifts though require people to operate them (1 to 2 persons) since automated operation has not been successfully developed. Generally, lifts and locks operate for 16 hours per day, 7 days a week. At this pace both mechanical and human problems are introduced at the collection and delivery areas (Bell 1984). The possible lower capital cost for fish lifts and locks must be measured against increased operational costs. These disadvantages have limited the use of both fish lifts and fish locks.

Unit costs for fish locks and fish lifts may range from $20,000 to $100,000 per m of passage height. Annual operation and maintenance costs, based on total unit costs, are estimated at 1% to 5% for fish locks and 1% to 14% for fish lifts (Hildebrand et al. 1980).

FISHWAYS AT CULVERTS

The passage of fish should be considered when culverts are placed in fish-bearing streams. Culverts may prevent fish from moving upstream if water velocities are high at the outlet, within the culvert or at the inlet; if the outlet is above stream grade; or if water depth in the culvert is low. Several recent reviews of fish passage requirements for culverts are available (Anonymous 1980; Dane 1978; Evans and Johnston 1980; LGL Limited 1983; Manitoba Fisheries Branch 1982; Katopodis 1981b; Saremba and Mattison 1984).

Setting the culvert a minimum of 300 mm below streambed solves many common problems at stream crossings. With such an installation fish have adequate water depth for swimming, and can enter the culvert easily, if water velocities are favourable. Back flooding (Fig. 9) eliminates the drop at the outlet of existing culverts. Adequate scour protection for the stream banks and bed prevents the formation of such drops.

Providing water velocities low enough for fish passage is a difficult task in plain culverts. Fish usually have to use their prolonged swimming speeds to negotiate a culvert. For salmon, Dane (1978) suggests that mean water velocities not exceed 1.2 m/s, for culverts less than 25 m, or 0.9 m/s for culverts 25-60 m long. Most freshwater fish require lower velocities than salmon (Manitoba Fisheries Branch 1982; Katopodis 1981b). Frequently, designing a plain culvert to meet such restrictive velocity criteria is not practically or economically feasible. This is particularly true for weak swimmers that migrate during periods of high stream flow. In these instances, fishways within the culvert or as separate structures through the embankment are used.

Fishways through the embankment are similar to those at dams and are designed the same way. Culvert fishways are usually arrangements of baffles in the form of plates, blocks, or sills attached to the bottom. Baffle systems provide resting areas at regular intervals and fish adopt a burst-rest pattern, advancing through the culvert in stages. The hydraulics of two culvert fishways, the offset (Fig. 10) and spoiler (Fig. 11) baffles, were studied in model and prototype (MacPherson and Kerpan 1983; Katopodis et al. 1978).

The burst speeds of passing fish limit the jet velocities between individual baffles, and sustained speeds limit the water velocities between rows of baffles. Fig. 12 provides jet velocities (V_j) in the two baffle systems of offsets and spoilers as a function of culvert slope (Katopodis et al. 1978). Jet velocities are expressed in terms of a Froude number based on the hydraulic radius of a plain culvert (R_p) with the same dimensions, slope and discharge as the baffled culvert. The effectiveness of spoilers and offsets in reducing jet velocities decreases as culvert slope increases. Baffles reduce the hydraulic efficiency of culverts and Fig. 13 provides a measure of this reduction. Fig. 13 shows the ratio of water depths between a culvert with baffles (d_t) and a plain culvert (d_p) as a function of the ratio of water depth to baffle height (d_p/h). At low discharges, when baffles are just submerged, large depth increases occur in the baffled culvert. At high discharges, when culvert capacity is a concern, depth increases are usually less than 20%.

Both the spoiler and offset baffles are adaptable to a variety of culvert shapes. A modified version of the spoiler baffles was used in the W. Darcy McKeough flood control scheme in Ontario to provide fish passage through a gated spillway (Meloche and McCorquodale 1984). Although field tests with the spoiler system are limited, experience with the offset system is extensive. Both salmon and freshwater species have used the offset baffles (Anonymous 1980; Dane 1978; Evans and Johnston 1980; MacPherson and Kerpan 1983).

Unit costs for the offset baffle system were about $650 per set of reinforced concrete baffles in a 1983 installation, while steel plate baffles would have cost about $1,100 (MacPherson and Kerpan 1983). Unit costs for a set (3.5 blocks) of metal spoiler baffles were about $800 in a 1975 installation (Katopodis et al. 1978).

During the design of the Liard Highway, Northwest Territories, the author advanced the "stream simulation" concept for fish passage at culvert crossings. In most cases, stream simulation provided a more economically viable alternative than the previously discussed methods (i.e. plain or baffled culverts). The stream simulation concept uses stream dimensions to size the culvert and uses large riprap within the culvert to resemble passable natural rapids. In practice, a culvert is selected which is of sufficent size to maintain average stream width and cross-sectional area for the stream discharge during fish migrations. The culvert is set at the average stream slope for the site, is placed below streambed, and is filled to stream grade. The top layer of the fill is non-uniformly laid riprap, large enough to be stable during the culvert design discharge.

Several Liard Highway culverts were constructed using the stream simulation approach. At four of these the performance of culvert fish passage was assessed (McKinnon and Hnytka 1984). This field study indicated that the culverts presented no difficulty to the spring migrations of arctic grayling and northern pike. Culvert velocities were comparable to the natural stream and no spawning migration delays were apparent. The presence of riprap, at least on one occasion, assisted the establishment of flow under the culvert ice and allowed fish to pass through the culvert without delay. With stream simulation, culvert construction has the potential for enhancing fish habitat. Gravel, placed or deposited naturally in the culvert, may provide habitat suitable for fish spawning (Kratt 1981).

FISH SCREENS

Water for agricultural use is diverted from streams and lakes which provide habitat for fish. Injury and mortality to fish, particularly the juvenile stages, may result from such water withdrawals. Screening facilities are used to protect fish at water intakes and diversion canals. Screen systems are based on four fish protection concepts: (a) fish collection and removal, (b) fish diversion, (c) fish deterrence, and (d) physical exclusion. Swimming ability, physical size and behaviour of fish are used to set guidelines for the design of screen systems.

Reviews of fish screening requirements include ASCE (1982), Anonymous (1980), Bell (1984), Clay (1961), Montreal Engineering (1979). British Columbia has the most extensive experience with fish screening projects in Canada and guidelines for stationary screens were developed there. The smallest fish to be protected determines the size of openings in the screen. Pink salmon fry formed the basis for setting a minimum clear opening of 2.5 mm. The sustained speeds of fish limit the approach velocities near the screen. From swimming tests and experience it was concluded that sustained speeds for Pacific salmon fry were 0.15 m/s. For screen design an approach velocity of 0.12 m/s was recommended. For self-cleaning screens this translates into a minimum unobstructed screen area of 8.2 m^2 per m^3/s of water. However, for intake screens which are not self-cleaning a minimum unobstructed screen area of 33 m^2 per m^3/s of water was recommended. An open screen area of at least 50% of the total screen area is required on all screens (Clay 1961). A basic design consideration at screen projects is the provision of a bypass channel or other means of transfering fish back to the stream.

Small, inexpensive screened intakes are shown in Fig. 14 for water withdrawals of less than 30 L/s. Simple fixed vertical screens are used on larger water intakes. The intake is normally located on the outside bend of the river and parallel to the direction of flow. A trashrack about 1.5 m from the screen protects the screen panels. Gates at the end of the screen gallery regulate flow, bypassing at least 50% of it downstream. A continuous washing action is created which keeps the screens clean. A low inclined weir across the river bottom ensures sufficient water depth by concentrating low flows on the intake side of the river (Anonymous 1980). Adaptations of several types of conventional vertical travelling screens are also used as fish screens in large water intakes.

The revolving-drum screen (Fig. 15) has been used on irrigation canals. A water driven paddlewheel system or an electric motor turns the drum. As the drum revolves, water passing through the screen removes debris on the downstream side. Drum screens may require frequent maintenance of seals and mechanical parts (Anonymous 1980). Clay (1961) quotes costs of about $5.30 per L/s for installations of 300 L/s or more, and maintenance costs of about 2% of the capital costs per year. A simple and less expensive alternative is the horizontal-vertical screen combination (Fig. 16). Experience with this screen system shows that only occasional cleaning is required after prolonged periods of operation (Anonymous 1980).

The Finnigan screen (Fig. 16) is a horizontal self-cleaning screen also used primarily on irrigation projects. A horizontal, smooth, perforated plate set flush with the bottom of the water diversion canal provides the screening area. Unscreened water flows down through the plate and out into the canal through a false bottom under the screen. Surplus water flows into a bypass channel and returns to the stream. The flow drives four horizontal paddles. As the paddle arms turn, brushes attached to them clean the screen. Fish and debris are readily directed into a collection bay and operation of a bypass gate allows fish and debris back into the stream. Gates and stoplogs are used to maintain proper water levels which are critical to the effective operation of the screen (Anonymous 1980). With treated wood construction, total cost for Finnigan screens has varied with installation capacity, from $3,000 for 140 L/s to $5,000 for 1400 L/s (Montreal Engineering 1979).

RESEARCH CONSIDERATIONS

Currently several studies related to fishway design are underway. These studies address the areas of fish biomechanics, fishway hydraulics, and field assessment of fishways. Extensive swimming performance data for some species are available in the literature, particularly from laboratory tests. In a cooperative effort between the Department of Fisheries and Oceans (Western Region) and Alberta Transportation these data have been deciphered and are analyzed by North/South Consultants Inc. (Winnipeg). The objective is to reduce the data to forms that can be used directly in fish passage design.

Hydraulic model studies with fishways initiated by the author in 1980 at the University of Alberta are continuing. These studies have been funded by the Department of Fisheries and Oceans (Western Region) and Alberta Environment. A study of backwater curves in Denil fishaways and their effects on discharges and water velocities is near completion. In the past year, research has focused on the vertical slot design. Model tests with two variations of this design were conducted. At least a full year of model tests is required to complete the study on vertical slot fishways.

Several field studies of fish passage performance in existing or experimental fishways were conducted recently (Dunn 1983; Fernet 1984; Tomich et al. 1982; Tredger 1982; Smith 1984). Such studies provide data on how effective fishways are in meeting the requirements of several fish species of western and northern Canada. Studies in fish biomechanics, fishway hydraulics, and field assessment of fishways should continue. The development of design criteria for effective fishways depends on the integration of the findings from these three areas of study.

Although progress has been made in designing culverts for fish passage, the task of providing effective designs both from the economic and resource conservation points of view is far from complete. Lack of information in several areas leads to ineffective solutions (e.g. inaction, half-measures, overdesign). The swimming performance study mentioned earlier is only a beginning for the development of effective design criteria. Several other areas need investigation. Such applied research areas are: (a) model studies on the hydraulics of several fish passage devices for culverts, (b) field studies on passage performance of culvert fishways, and (c) office and field studies on the relationship between fish migration and stream hydrology.

An investigation of the feasibility of protecting valuable fish resources at existing agricultural projects is needed. In new projects fish protection should be an integral part of the design process. Fish screening guidelines for species other than Pacific salmon are needed to assist the designer. The fish screening guidelines developed in British Columbia combined with knowledge of the specific characteristics and requirements of each species can lead to the formulation of such guidelines.

CONCLUSIONS AND RECOMMENDATIONS

1. Biological factors, such as life history, swimming ability, and behaviour of fish are fundamental in effective fish passage design. Site specific and species specific information is required. Funding should be provided to obtain such information whenever it is lacking.

2. Model studies on the hydraulics of fishways at dams and at culverts, as well as, field studies on fishway performance should continue.

3. Fish screening guidelines for species other than Pacific salmon should be developed.

4. The feasibility of protecting fish at existing agricultural projects should be investigated.

ACKNOWLEDGMENTS

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REFERENCES

Anonymous. 1980. Stream enhancement guide. Department of Fisheries and Oceans, Vancouver, British Columbia. v + 82 p. + 4 appendices.

ASCE. 1982. Design of water intake structures for fish protection. American Society of Civil Engineers, New York. 163 p.

Bell, M.C. 1984. Fisheries handbook of engineering requirements and biological criteria. US Army Corps of Engineers, North Pacific Division, Portland, Oregon. v + 290 p.

Clay, C.H. 1961. Design of fishways and other fish facilities. Department of Fisheries and Oceans, Queen's Printer, Ottawa. 301 p.

Dane, B.G. 1978. A review and resolution of fish passage problems at culvert sites in British Columbia. Can. Fish. Mar. Serv. Tech. Rep. 810: x + 126 p.

Decker, L.F. 1967. Fishways in Maine. Maine Department of Inland Fisheries and Game, Augusta, Maine. 47 p.

Dunn, C.L. 1983. Evaluation of the Katepwa vertical slot fishway. Saskatchewan Department of Parks and Renewable Resources, Saskatoon. 90 p.

Evans, W.A., and B. Johnston. 1980. Fish migration and fish passage, a practical guide to solving fish passage problems. US Department of Agriculture, Forest Service, Washington, D.C. xii + 63 p. + 7 appendices.

Fernet, D.A. 1984. An evaluation of the performance of the Denil 2 fishway at Fawcett Lake during the spring of 1983. Environmental Management Associates, Calgary, Alberta. 51 p. + 3 appendices.

Hildebrand, S.G., M.C. Bell, E.P. Richey, J.J. Anderson, and Z.E. Parkhurst. 1980. Analysis of environmental issues related to small scale hydroelectric development II: Design considerations for passing fish upstream around dams. Oak Ridge National Laboratory, ORNL/TM-7396, Oak Ridge, Tennessee. xii + 71 p.

Hoar, W.S., and D.J. Randall (Ed.). 1978. Fish physiology, Volume VII, Locomotion. Academic Press, New York. xviii + 576 p.

Katopodis, C. 1981a. Considerations in the design of fishways for freshwater species. Proceedings 5th Canadian Hydrotechnical Conference, Fredericton, N.B. p. 857-878.

Katopodis, C. 1981b. Review of culvert fish passage methods for freshwater species. Proceedings Resource Roads Workshops, Whitehorse and Yellowknife, Environmental Protection Service, Environment Canada, Ottawa. p. 202-220.

Katopodis, C., and N. Rajaratnam. 1983. A review and laboratory study of the hydraulics of Denil fishways. Can. Tech. Rep. Fish. Aquat. Sci. 1145: viii + 181 p.

Katopodis, C., and N. Rajaratnam. 1984. Similarity of scale models of Denil fishways. IAHR Symposium on Scale Effects in Modelling Hydraulic Structures, September 3-6, 1984. Technische Akademie Esslingen, W. Germany. H. Kobus (Ed.). p. 2.8-1 to 2.8-6.

Katopodis, C., P.R. Robinson, and B.G. Sutherland. 1978. A study of model and prototype culvert baffling for fish passage. Can. Fish. Mar. Serv. Tech. Rep. 828: v + 78 p.

Kratt, L.F. 1981. Evidence of arctic grayling (Thymallus arcticus) spawning in a highway culvert. Canadian Field-Naturalist, 95: 358.

LGL Limited. 1983. Urban development: guidelines for protection of fish habitat in insular Newfoundland. Department of Fisheries and Oceans, St. John's. vi + 95 p.

MacPherson, R.A., and K. Kerpan. 1983. Fish passage evaluation of a culvert with offset baffles. Draft manuscript report. Department of Fisheries and Oceans, Winnipeg, Manitoba.

Manitoba Fisheries Branch. 1982. Recommended fish protection procedures for stream crossings in Manitoba. Department of Natural Resources. v + 46 p.

Meloche, L., and J.A. McCorquodale. 1984. Design of a hydraulic control structure with an in-spillway fishpass. K.V.H. Smith (Ed.). Proc. 1st International Conference on Hydraulic Design in Water Resources Engineering: Channels and Channel Control Structures. April 11-13, 1984, Southampton, U.K. Computational Mechanics Centre. Springer-Verlag, New York. p. 4-115 to 4-129.

McKinnon, G.A., and F.N. Hnytka. 1984. Design and fish passage assessment of culverts constructed to simulate stream conditions on Liard River tributaries. Draft manuscript report. Department of Fisheries and Oceans, Winnipeg, Manitoba.

Montreal Engineering Company Limited. 1979. A study of fish screening and alternatives for regional water use projects in Canada. Department of Fisheries and Oceans, Ottawa. v + 92 p. + 4 appendices.

Rajaratnam, N., and C. Katopodis. 1984. Hydraulics of Denil Fishways. J. of Hydraulic Engineering, 110(9): 1219-1233.

Ruggles, C.P., and D.G. Murray. 1983. A review of fish response to spillways. Can. Tech. Rep. Fish. Aquat. Sci. 1172: ix + 31 p.

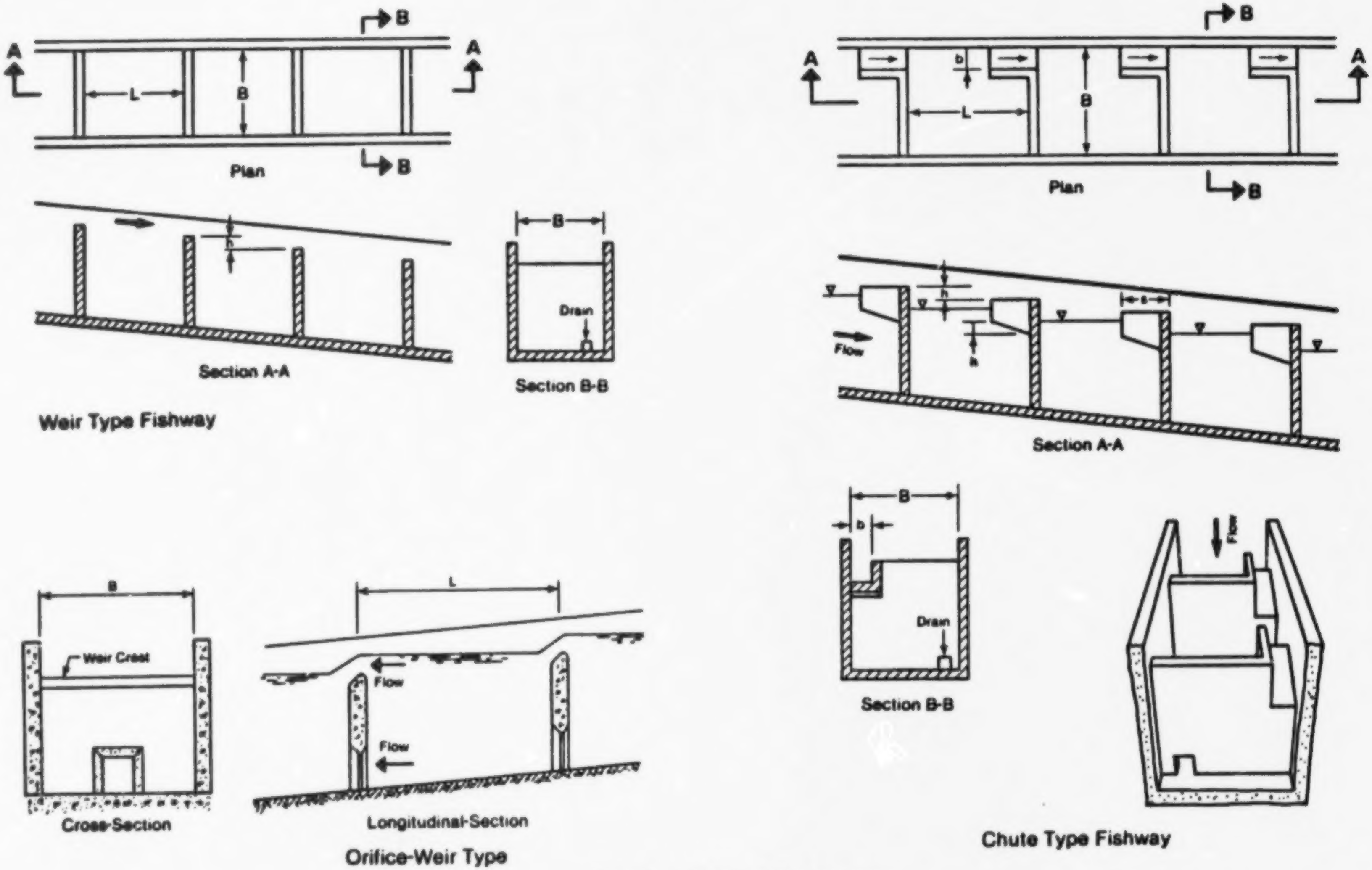
Saremba, J., and J.S. Mattison. 1984. Environmental objectives and procedures for water crossings. British Columbia Ministry of Environment, Victoria, Technical Report 6: xiii + 85 p.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184: xi + 966 p.

Smith, S.B. 1984. Evaluation of test fishways on Riviere des Rochers in the Peace-Athabasca Delta. Interim report. S.B. Smith Environmental Consultants Ltd., Edmonton, Alberta. 36 p.

Tomich, R.J., L.M. Jaremovic, and G.O. Stewart. 1982. Alberta Environmental evaluation of Prairie fishways. Envirocon Limited, Vancouver, B.C. 87 p. + 21 appendices.

Tredger, C.D. 1982. Experimental testing of kokanee (Oncorhynchus nerka) passage in an Aeroceanics spiral fishway at Meadow Creek, British Columbia. Manuscript report, B.C. Ministry of Environment, Victoria, B.C. 21 p.


A
B
L
B
Plan
B
A
h
Section A-A
B
Drain
Section B-B
Weir Type Fishway
B
Weir Crest
Cross-Section
L
Flow
Flow
Longitudinal-Section
Orifice-Weir Type
B
A
b
L
B
A
Plan
B
h
s
Flow
h
Section A-A
B
b
Drain
Section B-B
Flow
Chute Type Fishway

Pool and Weir Fishways

Fig. 1. Schematic representation of three variations of the pool and weir fishway. These are classical fish ladders, among the oldest and simplest designs. The chute type is a more recent development and is designed to ease passage of fish which do not surmount over falls, leap over obstacles or pass through submerged orifices.

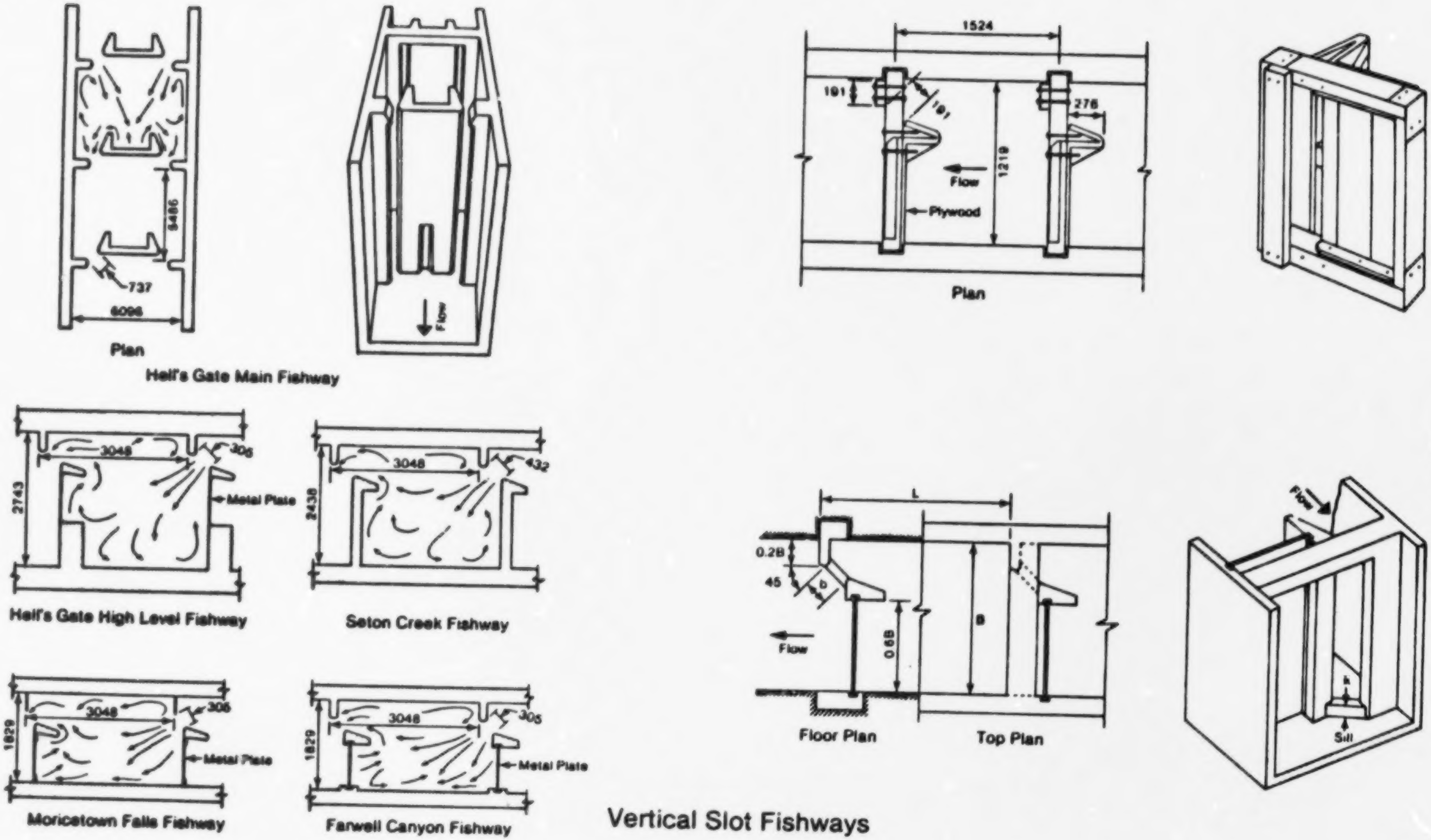

Plan
Hell's Gate Main Fishway
6096
5486
737
Flow
1524
191
191
278
1219
Flow
Plywood
Plan
Hell's Gate High Level Fishway
2743
3048
306
Metal Plate
Seton Creek Fishway
2438
3048
432
Moricetown Falls Fishway
1829
3048
305
Metal Plate
Farwell Canyon Fishway
1829
3048
305
Metal Plate
L
0.2B
45
b
0.6B
B
Flow
Floor Plan
Top Plan
Flow
h
Sill
Vertical Slot Fishways

Fig. 2. Examples of vertical slot fishways in British Columbia (Clay 1961 ; all dimensions in mm) and a generalized schematic representation. The vertical slot is self-adjusting and provides fish passage over a wide range of stream discharges.

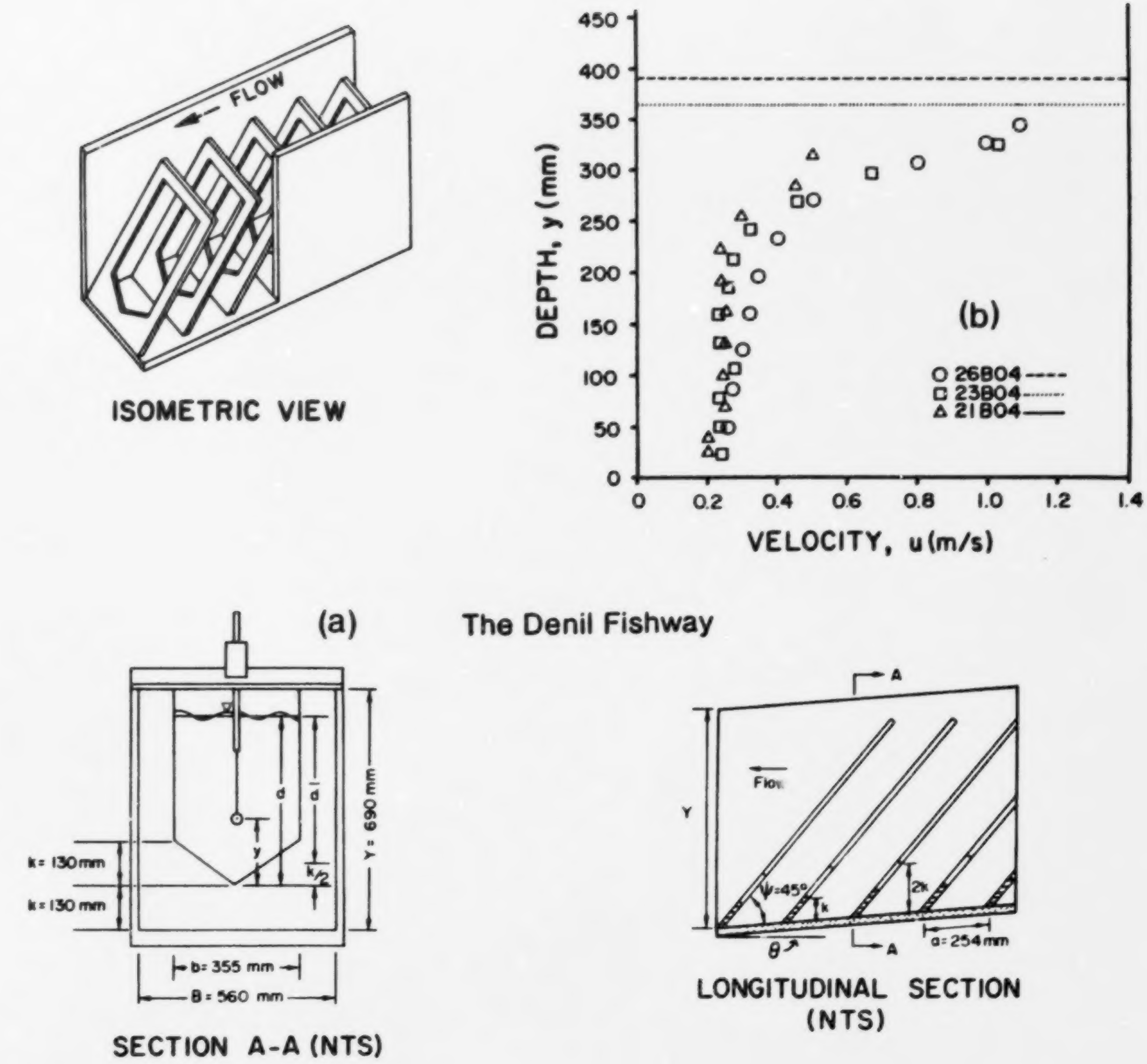

FLOW
ISOMETRIC VIEW
DEPTH, y (mm)
450
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
VELOCITY, u(m/s)
(b)
○ 26B04
□ 23B04
△ 21B04
(a)
The Denil Fishway
k = 130mm
k = 130 mm
d
d̄
y
k/2
Y = 690 mm
b = 355 mm
B = 560 mm
SECTION A-A (NTS)
A
Y
Flow
ψ=45°
k
2k
θ
a = 254mm
LONGITUDINAL SECTION
(NTS)

Fig. 3. (a) General outline of a Denil fishway. The dimensions shown are for a "standard" Denil.
(b) Typical velocity profile along the fishway centerline.

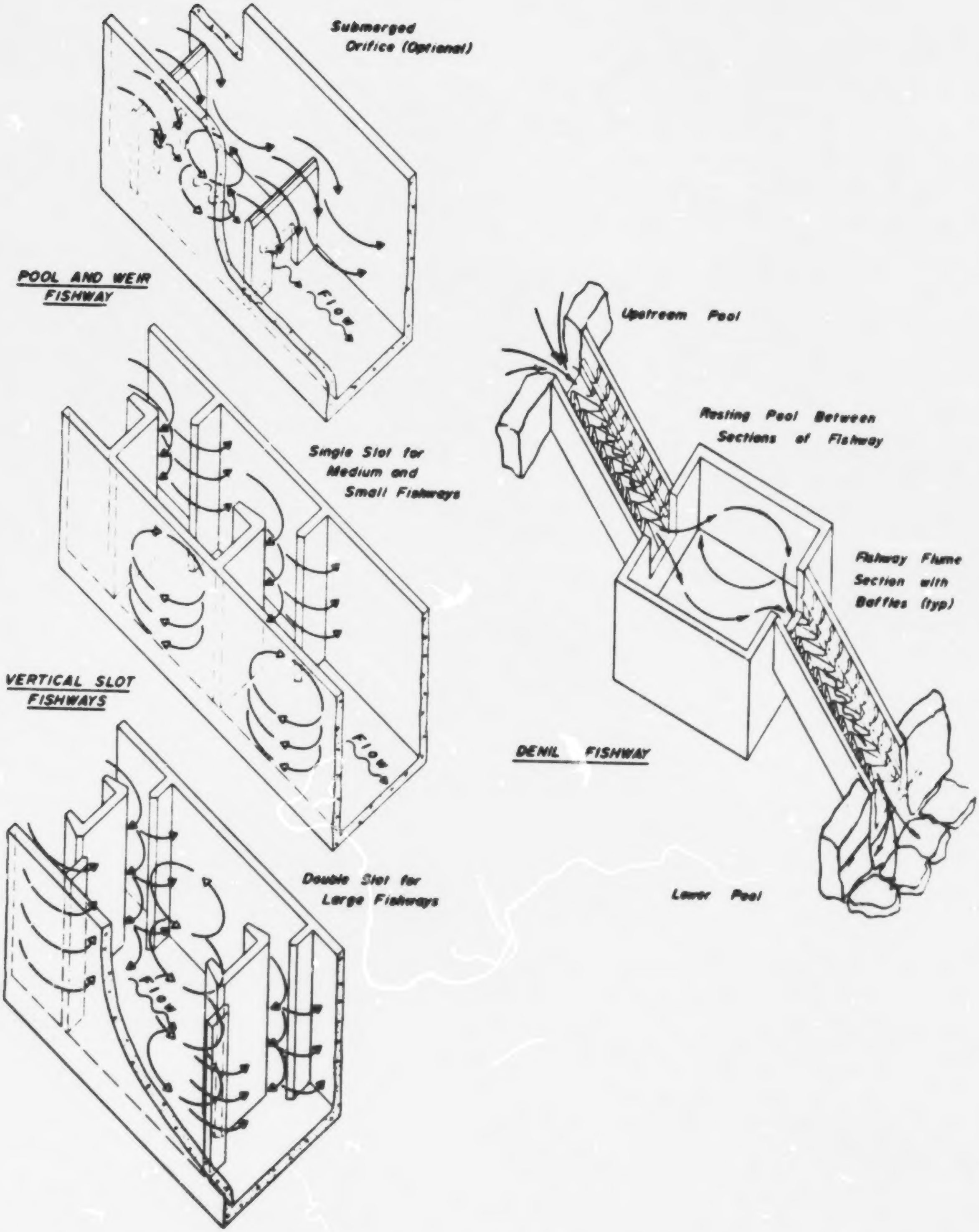

Submerged
Orifice (Optional)
POOL AND WEIR
FISHWAY
Flow
Single Slot for
Medium and
Small Fishways
VERTICAL SLOT
FISHWAYS
Flow
Double Slot for
Large Fishways
Flow
Upstream Pool
Resting Pool Between
Sections of Fishway
Fishway Flume
Section with
Baffles (typ)
DENIL FISHWAY
Lower Pool

Fig. 4. General outline and operational characteristics of pool and weir, vertical slot and Denil fishways (Anonymous 1980).

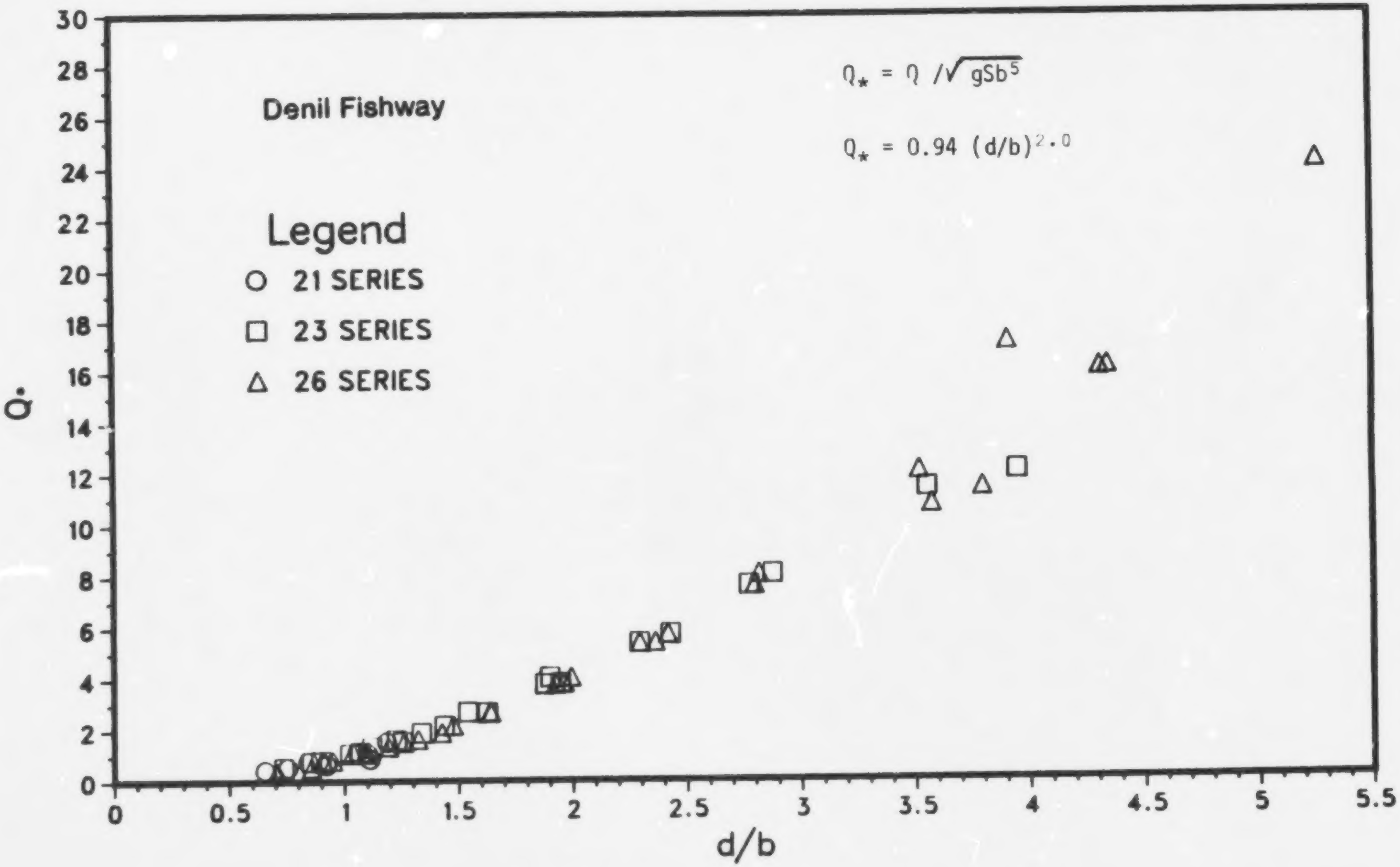


Fig. 5. The discharge rating curve for the "standard" Denil fishway. S is the fishway slope. For other symbols and dimensions refer to Fig. 3.

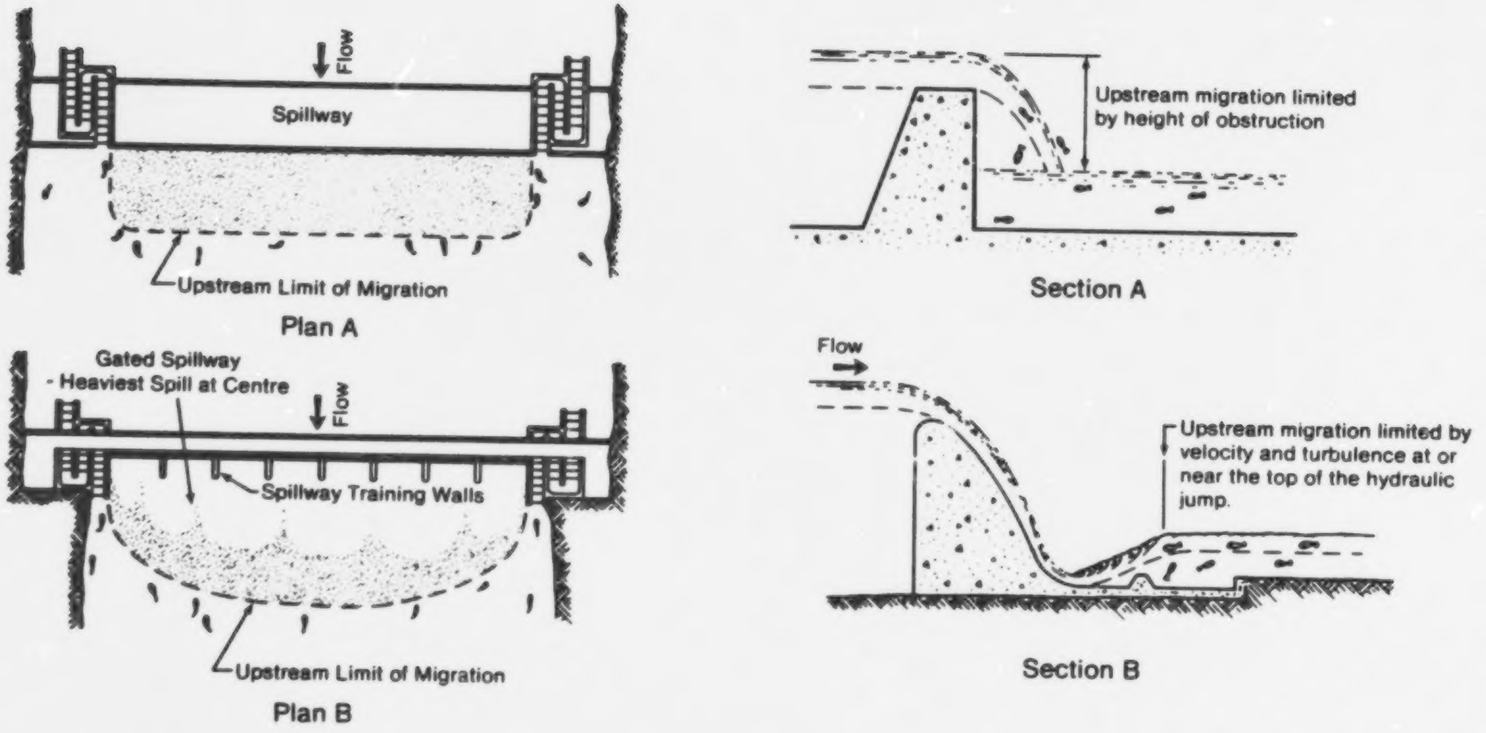
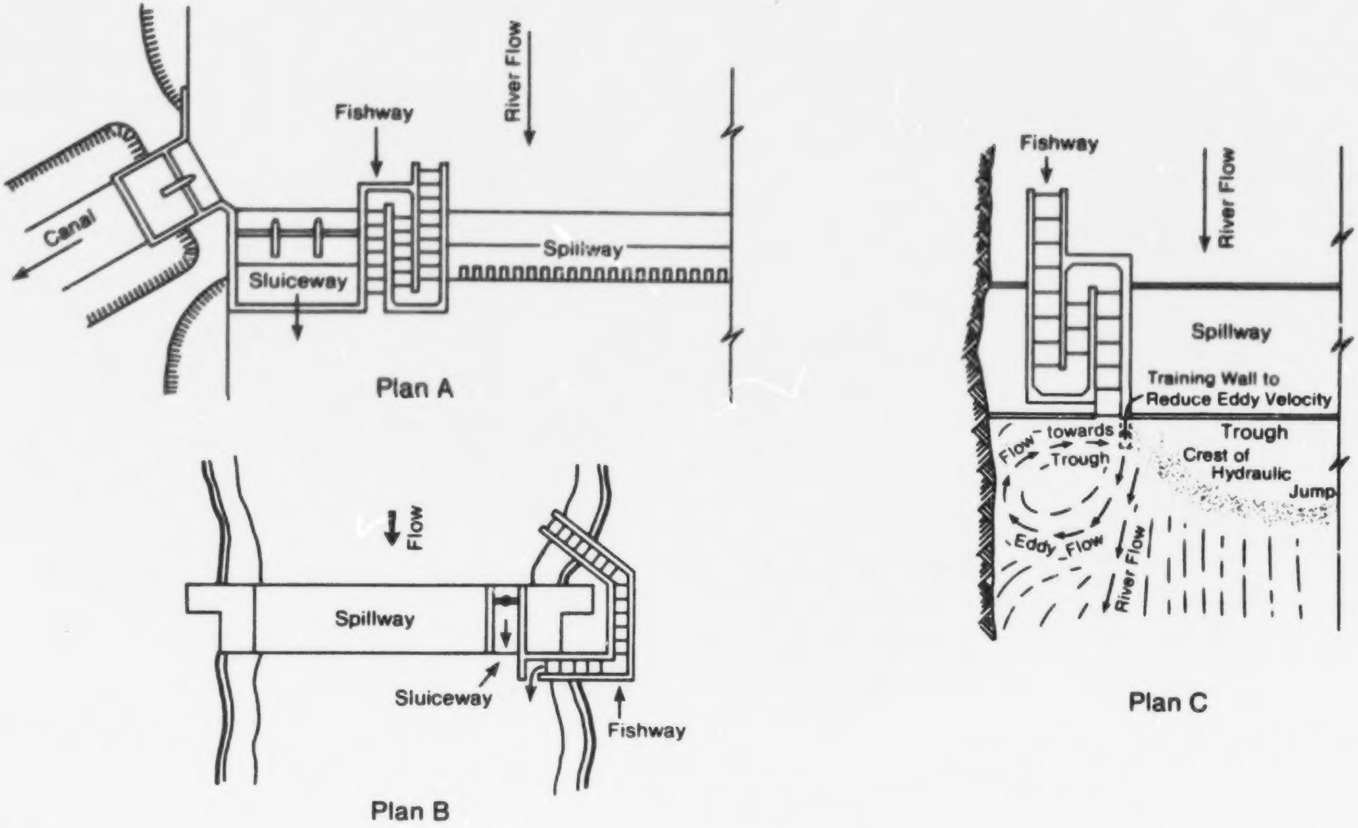

Flow
Spillway
Upstream Limit of Migration
Plan A
Gated Spillway
- Heaviest Spill at Centre
Flow
Spillway Training Walls
Upstream Limit of Migration
Plan B
Upstream migration limited
by height of obstruction
Section A
Flow
Upstream migration limited by
velocity and turbulence at or
near the top of the hydraulic
jump.
Section B

Fig. 6. Two schematic plans and typical cross-sections, showing a free crest and a gated spillway, and illustrating the position of the upstream limit of fish migration below dams and the location of fishways (Clay 1961).

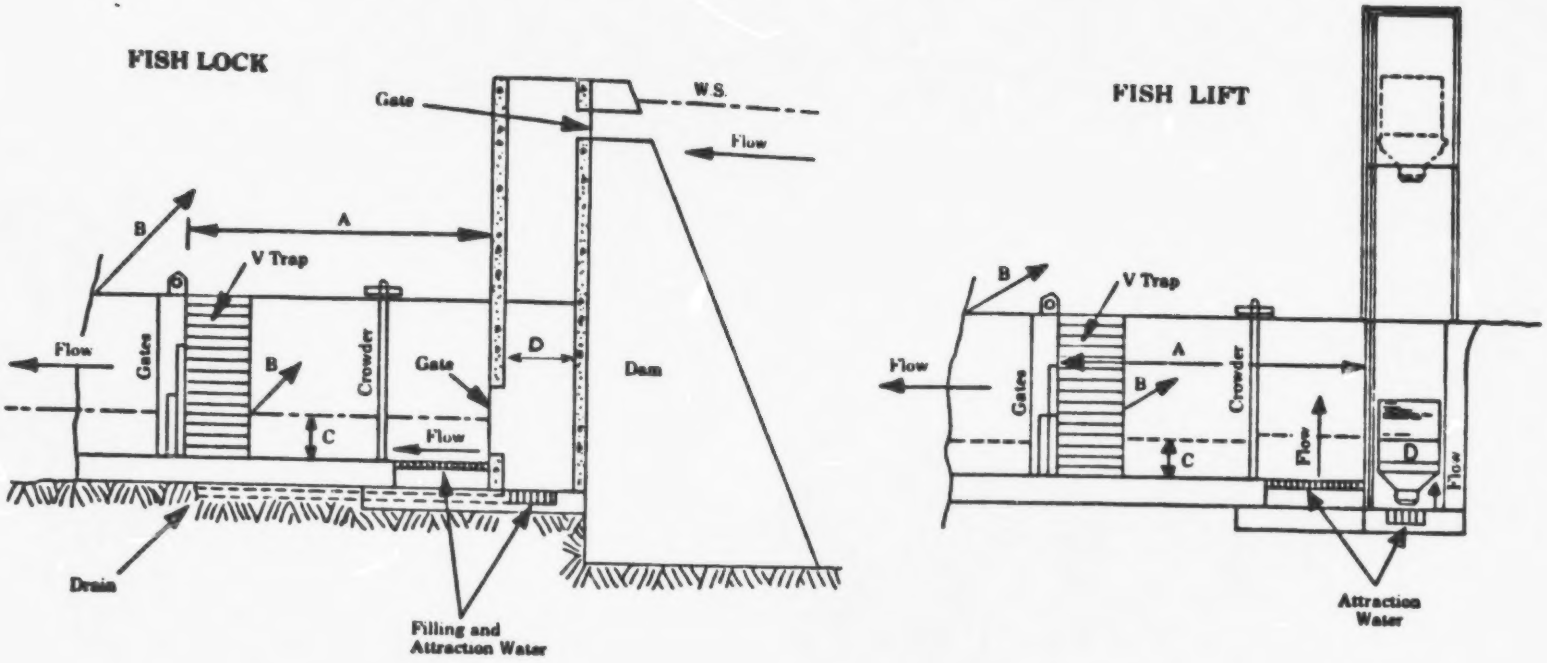

Fishway
River Flow
Canal
Spillway
Sluiceway
Flow
Spillway
Sluiceway
Fishway
Fishway
River Flow
Spillway
Training Wall to Reduce Eddy Velocity
Trough
Flow towards Trough
Crest of Hydraulic Jump
Eddy Flow
River Flow

Plan A

Plan B

Plan C

Fig. 7. Plans A and B illustrate fishway placement at dams and Plan C (Clay 1961) illustrates the probable direction of currents below the abutment of a typical dam. A large, strong eddy is undesirable.


FISH LOCK
Gate
W.S.
Flow
A
B
V Trap
Flow
Gates
B
Crowder
Gate
D
Dam
C
Flow
Drain
Filling and Attraction Water
FISH LIFT
B
V Trap
Flow
Gates
A
B
Crowder
Flow
D
Flow
C
Attraction Water

A Pool Length (m)	2.4	3.6	5.0
B Pool Width (m)	1.2	1.8	2.5
C Water Depth (Min) (m)	1.0	1.0	1.0
D Lock Chamber			
Discharge Variable (Min) (L/S)	850	850	850

A Pool Length (m)	2.4	3.6	5.0
B Pool Width (m)	1.2	1.8	2.5
C Water Depth (Min) (m)	1.0	1.0	1.0
D Hopper Size (m^3)	1.0	2.0	3.0
Discharge Variable (Min) (L/S)	850	850	850

Fig. 8. Schematic representations and typical dimensions of fish lock and fish lift systems (Bell 1984).

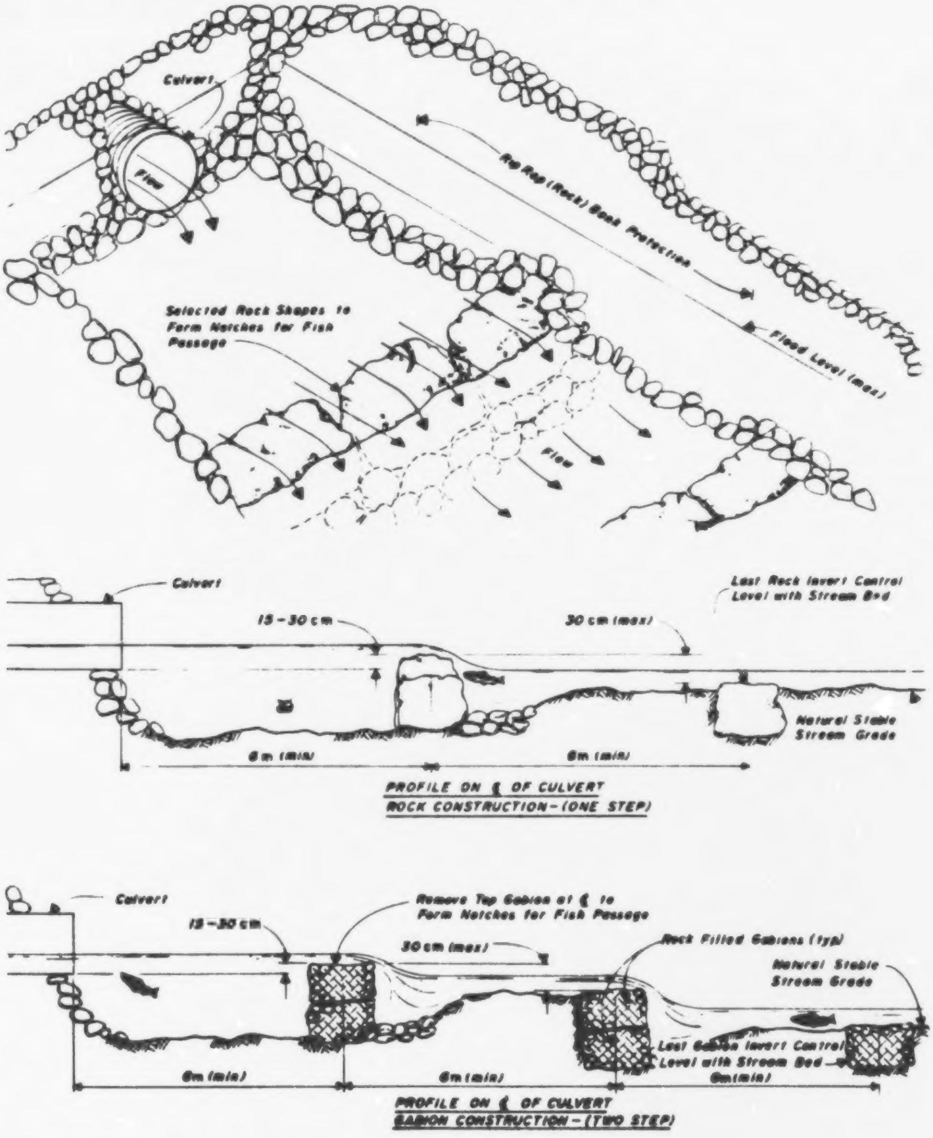

Culvert
Flow
Rip Rap (Rock) Bank Protection
Flood Level (max)
Selected Rock Shapes to Form Notches for Fish Passage
Flow
Culvert
15 - 30 cm
30 cm (max)
Last Rock Invert Control Level with Stream Bed
Natural Stable Stream Grade
6 m (min)
6m (min)
PROFILE ON ℄ OF CULVERT
ROCK CONSTRUCTION - (ONE STEP)
Culvert
15 - 30 cm
Remove Top Gabion at ℄ to Form Notches for Fish Passage
30 cm (max)
Rock Filled Gabions (typ)
Natural Stable Stream Grade
Last Gabion Invert Control Level with Stream Bed
6m (min)
6m (min)
6m (min)
PROFILE ON ℄ OF CULVERT
GABION CONSTRUCTION - (TWO STEP)

Fig. 9. Improving fish passage by back flooding an existing culvert to eliminate the drop at the outlet. The banks and streambed must be stabilized with rip-rap or gabions (Anonymous 1980).

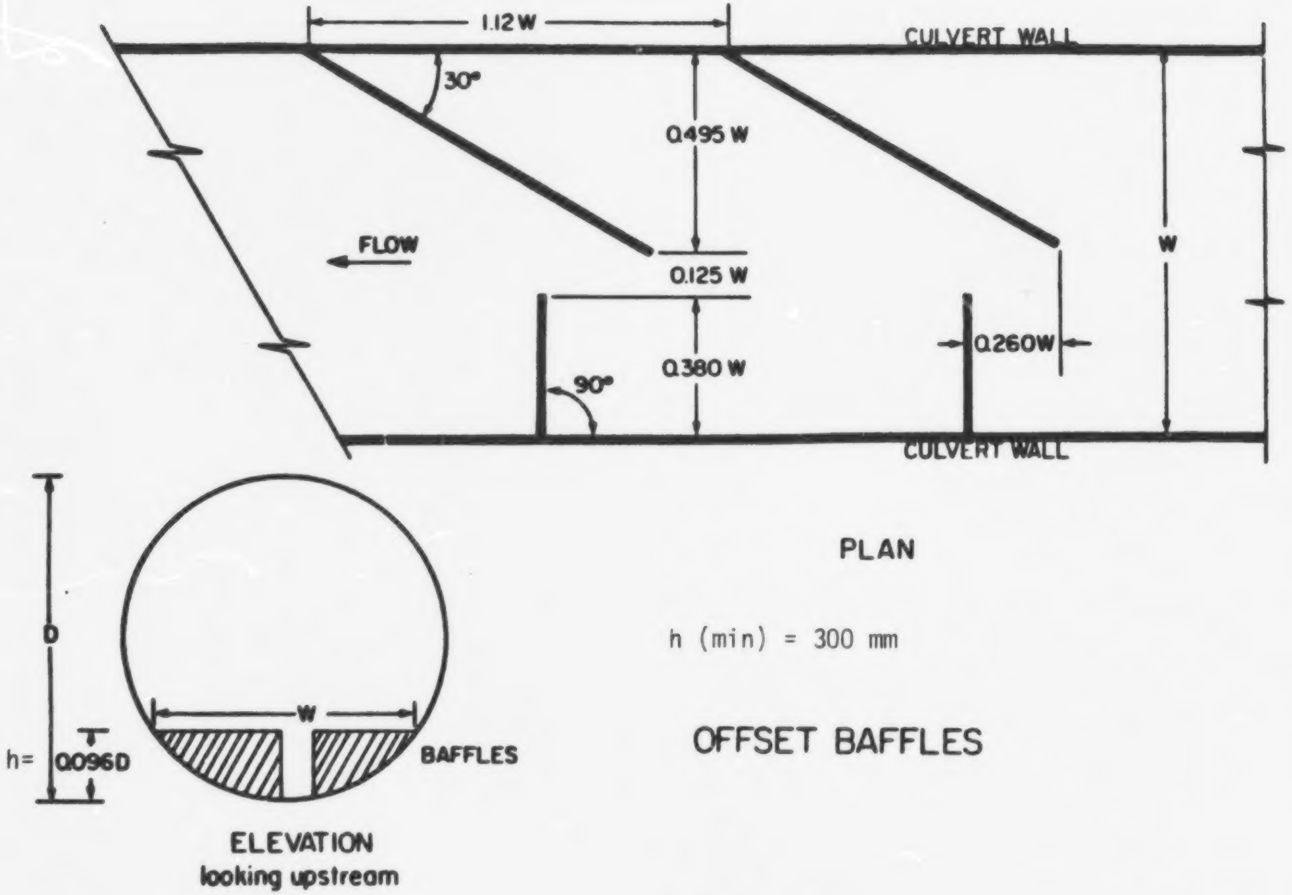

1.12 W
CULVERT WALL
30°
0.495 W
FLOW
0.125 W
0.380 W
90°
0.260W
W
CULVERT WALL
D
W
h=
0.096D
BAFFLES
ELEVATION
looking upstream
PLAN
h (min) = 300 mm
OFFSET BAFFLES

Fig. 10. A generalized schematic of the offset baffle system. Culvert fishways improve fish passage.

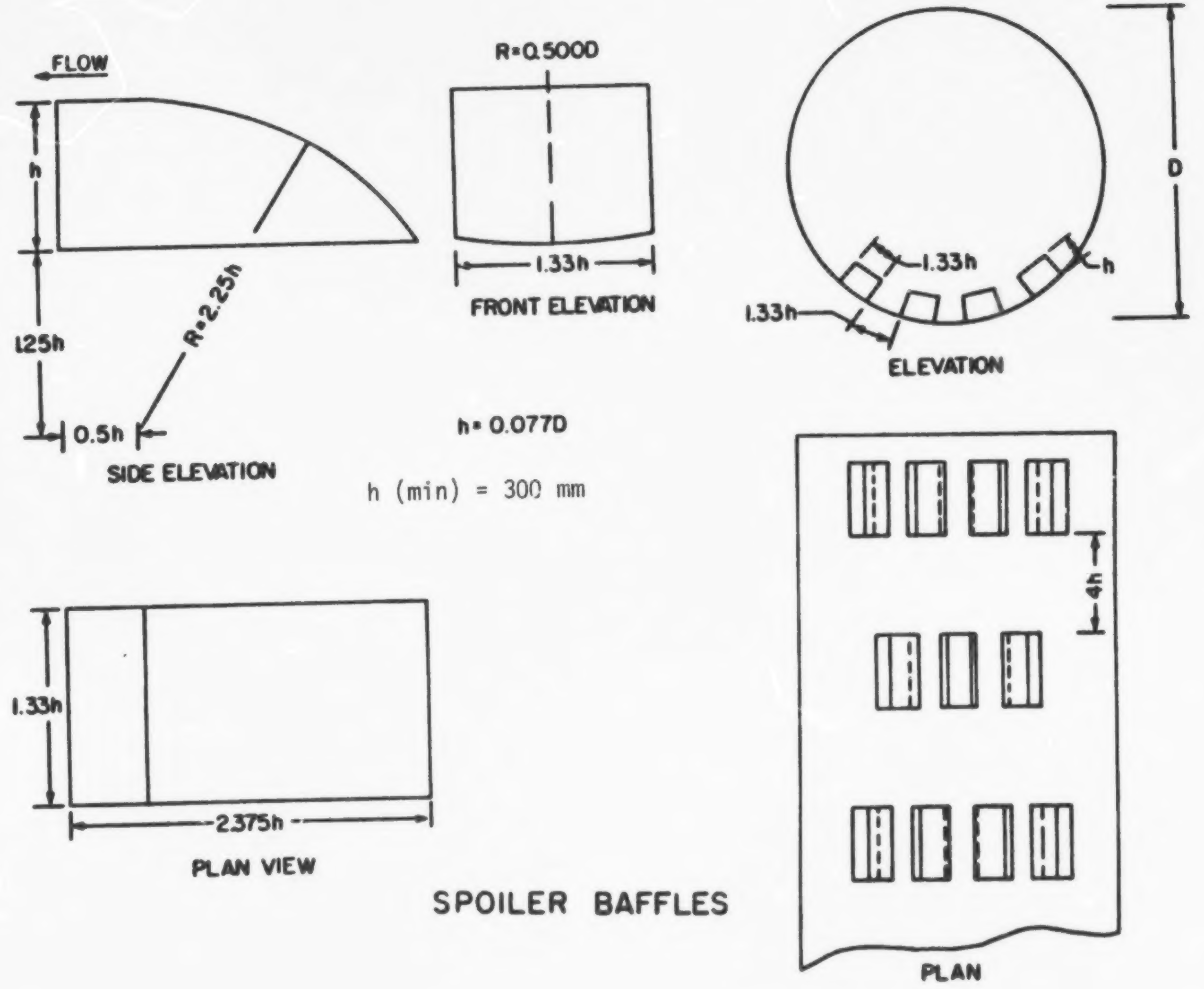

FLOW
h
1.25h
R=2.25h
0.5h
SIDE ELEVATION
R=0.500D
1.33h
FRONT ELEVATION
h= 0.077D
h (min) = 300 mm
1.33h
1.33h
h
D
ELEVATION
1.33h
2.375h
PLAN VIEW
SPOILER BAFFLES
4h
PLAN

Fig. 11. A general outline of the spoiler baffle system for circular culverts.

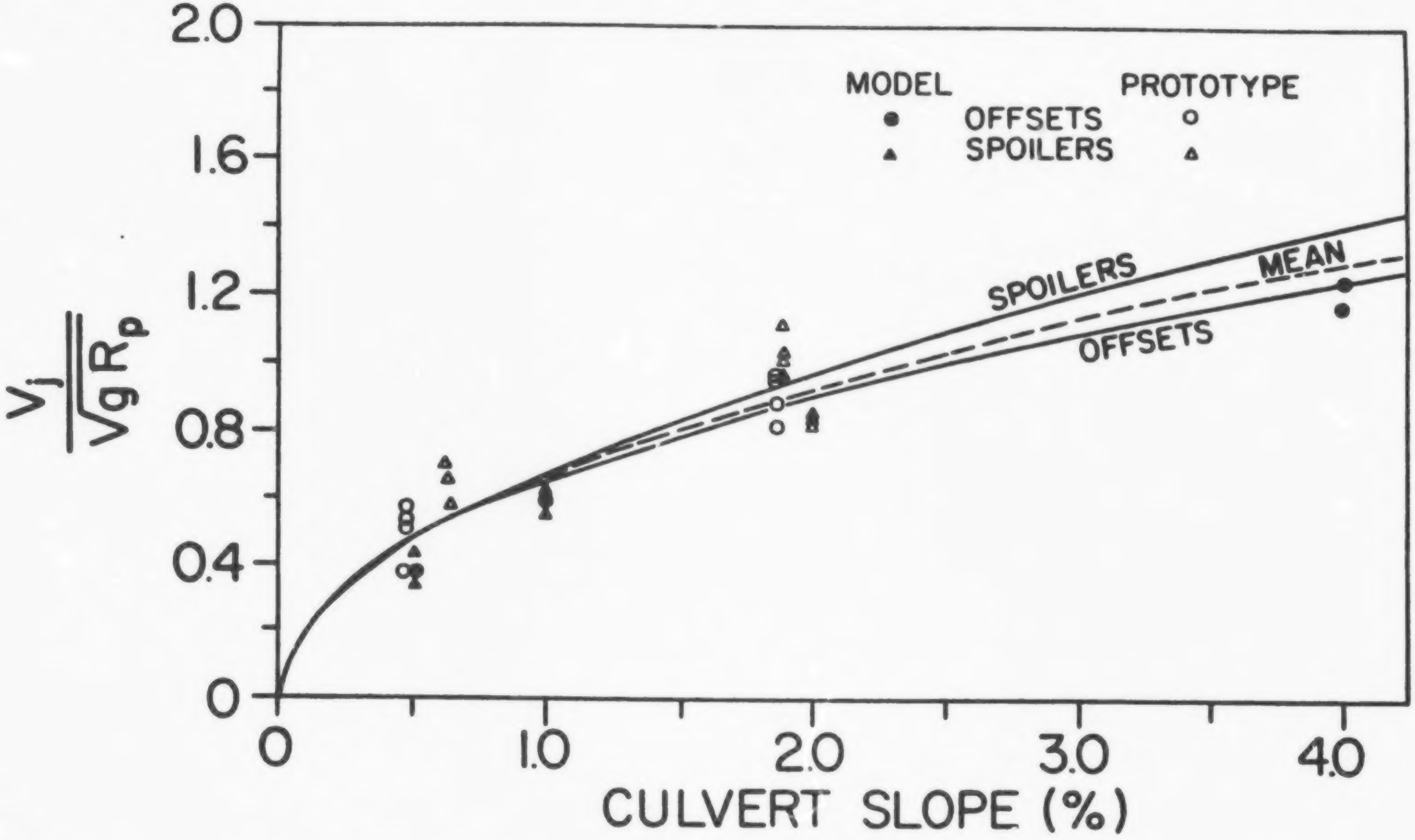


Fig. 12. Jet velocities (V_j) in the slots between baffles as a function of culvert slope. The hydraulic radius (R_p) is based on culvert flow without baffles (Katopodis et al. 1978).

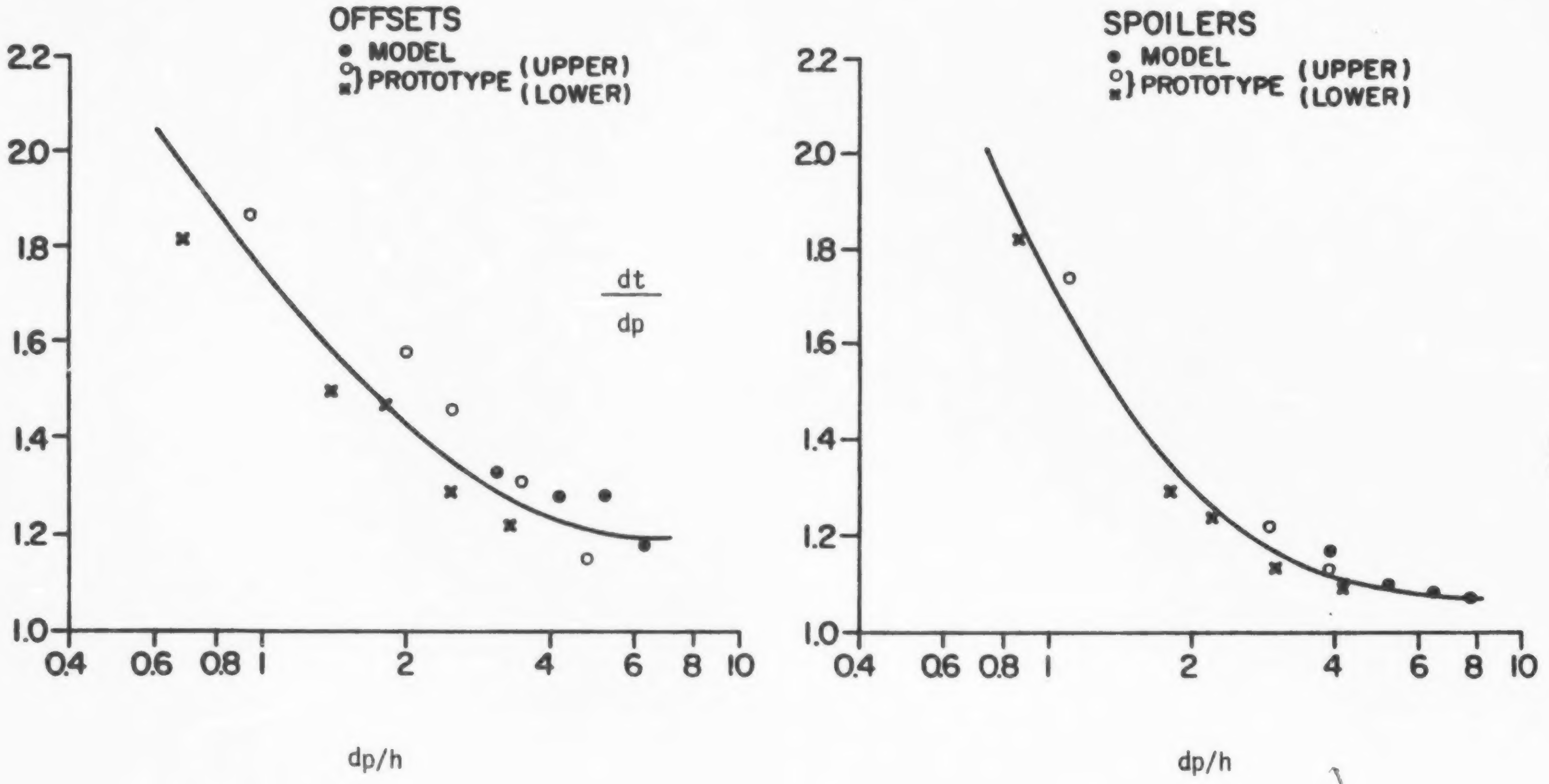
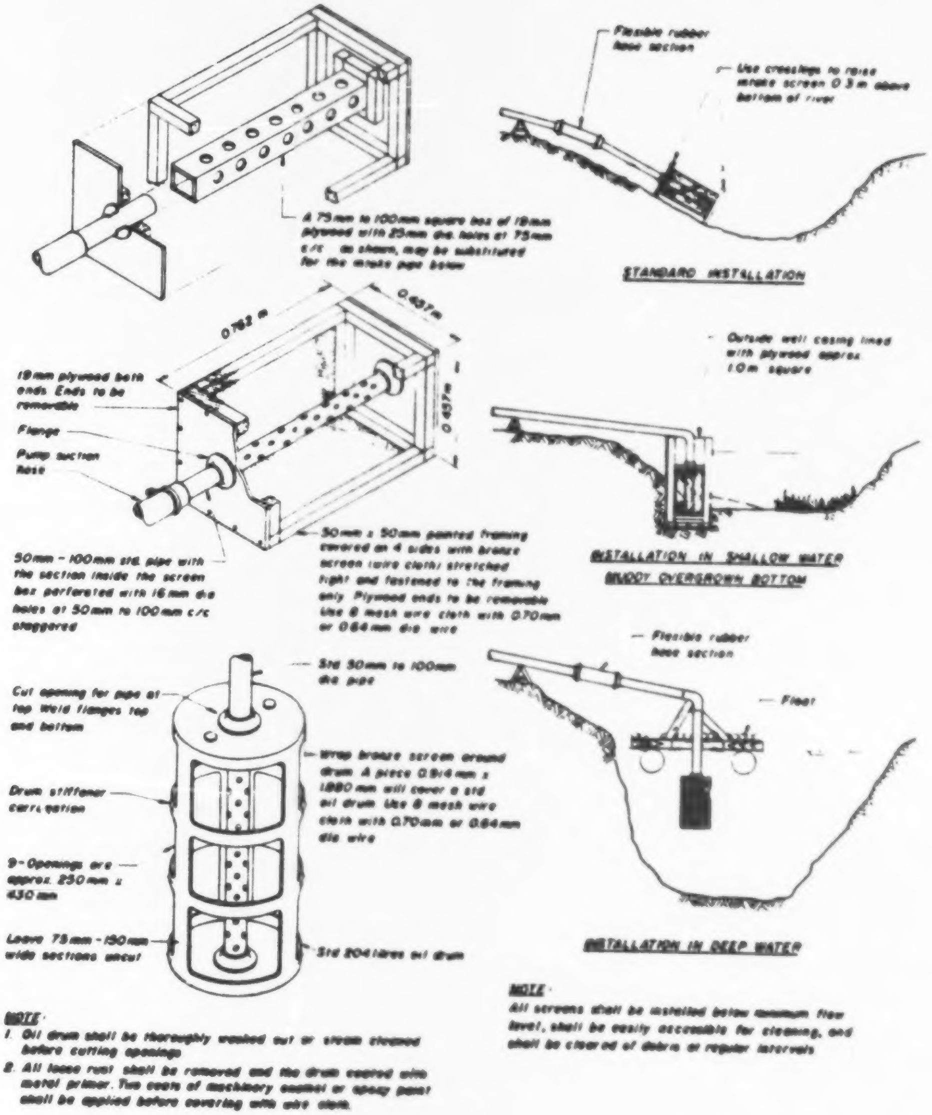


Fig. 13. Flow depth in a culvert with baffles (dt) is larger than in a plain culvert (dp) for the same diameter, slope and discharge. The flow depth ratio (dt/dp) decreases rapidly as the baffles are submerged (Katopodis et al. 1978).


A 75mm to 100mm square box of 19mm plywood with 25mm dia. holes at 75mm c/c as shown, may be substituted for the intake pipe below
Flexible rubber hose section
Use crossings to raise intake screen 0.3m above bottom of river
STANDARD INSTALLATION
0.762 m
0.437m
0.437m
19mm plywood both ends. Ends to be removable
Flange
Pump suction hose
50mm - 100mm std. pipe with the section inside the screen box perforated with 16mm dia holes at 50mm to 100mm c/c staggered
50mm x 50mm painted framing covered on 4 sides with bronze screen (wire cloth) stretched tight and fastened to the framing only. Plywood ends to be removable. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia wire
Outside well casing lined with plywood approx. 1.0m square
INSTALLATION IN SHALLOW WATER MUDDY OVERGROWN BOTTOM
Std 50mm to 100mm dia pipe
Cut opening for pipe at top. Weld flanges top and bottom
Wrap bronze screen around drum. A piece 0.914mm x 1880mm will cover a std oil drum. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia wire
Drum stiffener corrugation
9-Openings are approx. 250mm x 430mm
Leave 75mm - 150mm wide sections uncut
Std 204 litres oil drum
Flexible rubber hose section
Float
INSTALLATION IN DEEP WATER

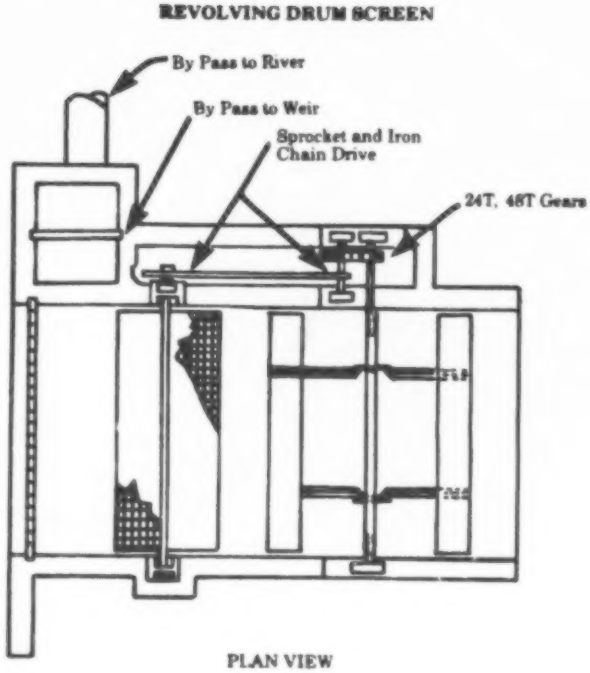
NOTE:

1. Oil drum shall be thoroughly washed out or steam cleaned before cutting openings.
2. All loose rust shall be removed and the drum coated with metal primer. Two coats of machinery enamel or epoxy paint shall be applied before covering with wire cloth.

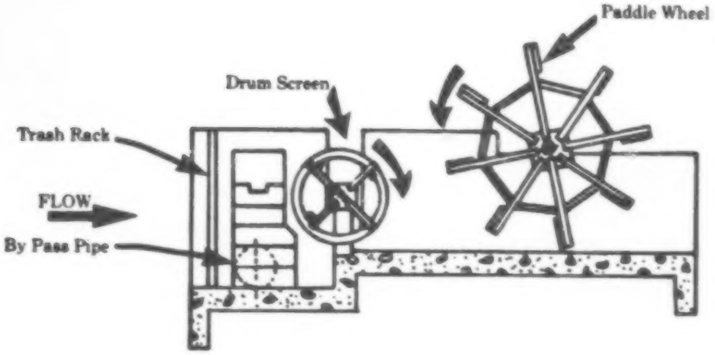
NOTE:

All screens shall be installed below minimum flow level, shall be easily accessible for cleaning, and shall be cleared of debris at regular intervals.

Fig. 14. Intake screens for pumps with capacities less than 30 L/s (Anonymous 1980).

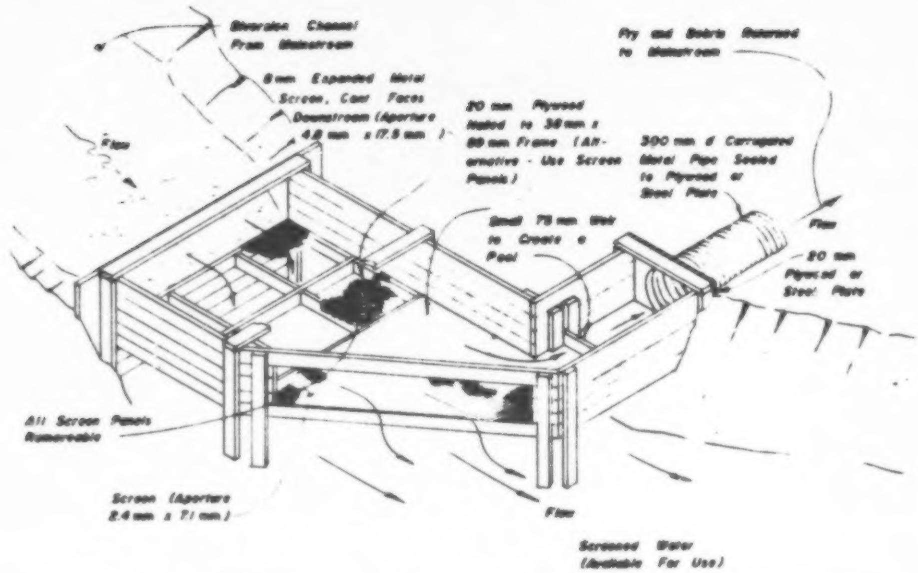

REVOLVING DRUM SCREEN
By Pass to River
By Pass to Weir
Sprocket and Iron Chain Drive
24T, 48T Gears

PLAN VIEW

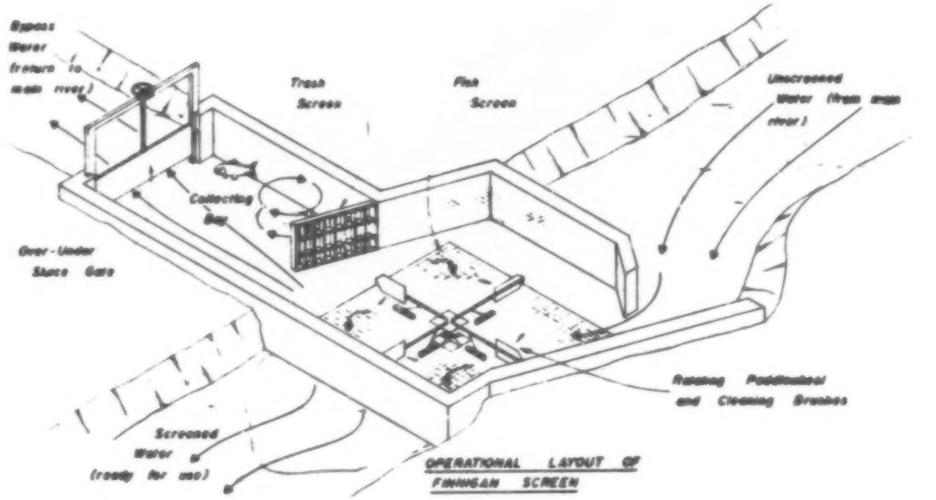

Paddle Wheel
Drum Screen
Trash Rack
FLOW
By Pass Pipe

SECTION

Fig. 15. Paddle wheel driven drum screen with a bypass pipe allowing small fish to escape (Bell 1984) Instead of the paddle wheel, an electric motor may be used to rotate the drum.


Diversion Channel From Mainstream
Fry and Debris Returned to Mainstream
6 mm Expanded Metal Screen, Cut Faces Downstream (Aperture 4.8 mm x 17.5 mm)
Flow
20 mm Plywood Nailed to 38 mm x 89 mm Frame (Alternative - Use Screen Panels)
300 mm ⌀ Corrugated Metal Pipe Sealed to Plywood or Steel Plate
Small 75 mm Weir to Create a Pool
Flow
20 mm Plywood or Steel Plate
All Screen Panels Removeable
Screen (Aperture 2.4 mm x 7.1 mm)
Flow
Screened Water (Available For Use)

Horizontal-vertical screening facility located in a diversion channel off the main stream. Water flows through the horizontal and vertical sections of screen and is available for use in the irrigation channel or other water use facility downstream. Fish and debris are guided to the bypass culvert which discharges back to the main stream.


Bypass Water (return to main river)
Trash Screen
Fish Screen
Unscreened Water (from main river)
Collecting Bay
Over-Under Sluice Gate
Rotating Paddlewheel and Cleaning Brushes
Screened Water (ready for use)
OPERATIONAL LAYOUT OF FINNIGAN SCREEN

Horizontal self cleaning water screen. Water is diverted from the main stream through a bypass channel. Water and fish pass over the horizontal screen and back into the main stream. Water levels are maintained by a simple gate device and/or stop logs. The water that passes through and below the screen is available for use in the irrigation channel or other water use facility.

Fig. 16. The horizontal-vertical screen (top) and the Finnigan screen (Anonymous 1980).

DESIGN AND CONSTRUCTION
OF THE
NAMEPI-KENNEDY DRAINAGE PROJECT
IN
ALBERTA

DESIGN AND CONSTRUCTION OF
THE NAMEPI-KENNEDY DRAINAGE PROJECT
IN ALBERTA

D.H. Lindner[1]

SYNOPSIS

The Namepi-Kennedy Creek Drainage Basin is located approximately 75 kilometres northeast of Edmonton, Alberta and covers about 650 square kilometres. In response to long-standing agricultural drainage and flooding problems, Alberta Environment in 1977 initiated construction of a staged multi-million dollar drainage improvement project. The Namepi-Kennedy project consists primarily of channel improvement and upgrading of associated works to increase conveyance capacity of the two creeks, thereby enhancing drainage of adjacent agricultural lands.

Design flows up to 36 cubic metres per second have a 5-year return period. Construction was done annually during the June-December period. The paper emphasizes the engineering aspects of design and construction associated with the sequential implementation program.

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DESIGN AND CONSTRUCTION OF THE NAMEPI-KENNEDY DRAINAGE PROJECT IN ALBERTA

INTRODUCTION

This project describes the major features of the Namepi-Kennedy Drainage Project located approximately 75 km northeast of Edmonton, Alberta, and designed and constructed during the period from 1977 to 1984. Figure 1 gives the location of the project.

PROJECT SETTING

The Basin

The drainage area of Namepi Creek and Kennedy Creek, from which the project name is derived, covers approximately 650 square kilometres. Namepi Creek begins about 42 km north of the Village of Radway and eventually discharges into the North Saskatchewan River. Kennedy Creek, 27 km in length, drains the northwest portion of the basin and flows past the Village of Thorhild joining Namepi Creek approximately 5 km north of Radway. Two primary highways and two railways cross the basin as indicated on Figure 2.

Climate

Climatological data and physical features as determined from standard references (19) are given below. The mean annual temperature range for the region is from 13° to 16°C. During the winter period less than 10 days have temperatures higher than 4°C and during the summer 15 to 25 days exceed 27°C. The frost free period is from 80 to 120 days and as such affects agricultural use.

Mean annual snowfall is in the range from 1000 to 1500 mm with mean precipitation in the range from 400 to 500 mm. Annual variability is approximately ± 30%.

Soils and Land Use

The soils of the region are classified as dark grey and dark grey wooded soils, with 60 to 75% of the land considered arable.

The 1976 Agricultural Census for the County of Thorhild which emcompasses the project area reveals that 72.5 percent (296,000 acres) were cultivated and 27.5 percent (111,000 acres) were unimproved. Of the improved acreage, 47 percent was under crop, 11 percent pasture and 12 percent was summer fallowed. The cropping pattern show that barley, tame hay, oats, wheat and canola account for 36, 31, 20, 7 and 4 percent of the acreage, respectively. The remaining unimproved lands consist of 7 percent woodlands and 20 percent in sloughs, wetlands, brush pasture and other forms of wasteland.

Flooding and Drainage Problems

Reports from the early 1940's point to flooding problems within the Namepi-Kennedy Creek drainage basin. Since that time, flooding has intensified due to additional land clearing, road construction and more intensive use of lands within the basin.(7) Comprehensive data on the extent of flooding for the period is not available. No gauging stations were in place before 1975 making frequency determinations difficult. It has been estimated that the 1965 flood (1:10 year event) and 1974 floods (1:40 year event) innundated 1600 acres and 3300 acres respectively.(5). Periodic spring flooding occurs primarily along the creek channels. However inadequate drainage exists throughout much of the basin making county roads impassable and causing inconvenience to residents. This situation adversely affects agricultural production and impedes efficient farming practices. During peak runoff periods an estimated 6700 acres of agricultural land are adversely affected.

History and Early Studies

While reports of flooding date back to the 1940's, little was done to solve the problem. Requests for offstream drainage were not approved by the Water Resources Division because of the limited channel capacity of the two major creeks. The first engineering study(2) to address the problem was done in 1969 by consultants retained by the Department of Environment, but the costs of the project were beyond the capability of the County to cost-share. Estimated costs were about $2.7 million to accommodate the 1 in 5 year event. Upon representations by the local authority and in recognition of the magnitude of the problem, the project was declard a "provincial project" in 1976. As such the Department of Environment provides funding for all construction while the County has the responsibility for obtaining all easements and right of ways and also all operation and maintenance upon completion. The works were phased over several years consistent with budget allocations. The project, as approved, was to extend north on Kennedy Creek to Township 61 and to Township 62 on Namepi Creek. However in 1982 at the request of the County, the project was extended northward an additional 7 km on Namepi Creek.

IMPLEMENTATION PROGRAM

With the implementation decision made in 1976, final design of works in the lower reach in the vicinity of Radway was begun using the consultants preliminary report as a guide. A geotechnical investigation and analysis along with a river engineering study necessitated basic design changes. Channel side slopes were flattened to 4.5H:1V and design water velocities were lowered. Straightening of the channel by cutoffs increased the channel gradient necessitating a series of drop structures for grade control. This in turn led to a total projected cost of about $7.7 million for the project.

Phasing

The project was divided into three distinct phases. Phase I extends northward for about 11.1 km along Namepi Creek to its confluence with Kennedy Creek. Construction of Phase I was done from 1977 to 1980. Phase II includes all work on Namepi Creek north of this point, while Phase III consists of all such works in Kennedy Creek. Construction on Phase II and III began in the winter of 1979-80 and will be completed during the 1984-85 fiscal year. Phasing of construction is also indicated in Figure 2.

Elements of Work

The primary elements of the works for all three phases are very similar. They basically consist of channel improvements, brushing, levelling, grading and reclaiming of adjacent lands, construction of grade control structures, rebuilding and modifying road bridges and farm crossings and accommodating utilities and similar improvements as required. The design and construction aspects for these elements which makeup the basic drainage system are addressed in subsequent sections.

DESIGN CONSIDERATIONS

Design Flow

Flow estimates for the 1 in 5 year event were adopted for final design of the various component works. Flows range from 6.2 m^3/s to 36.1 m^3/s on Namepi Creek and 6.2 m^3/s to 10.8 m^3/s on Kennedy Creek as indicated on Figure 3. These flows were used for the design of the channel, grade control structure, and bridges. Subsequent discussion will focus on these particular elements to illustrate typical design considerations.

Channel Parameters

As previously noted, the initial geotechnical investigation, consisting of boreholes at 33 locations for Phase I, and subsequent analysis revealed great variability in the material and the presence of considerable silt, silt shale material and coal seams at channel bed elevations. This resulted in 4.5H:IV side slopes, the reduction of design water velocities to less than 1 m/s and flatter channel gradients. Channel improvements also called for cutoff construction to be worked out in consultation with landowners. The net effect of cutoffs was the shortening of the channel by about one-third. Design work to arrive at the eventual channel parameters followed standard references (12, 16, 18) and was done by the River Engineering Branch and the Design Branch of the Department. Table 1 summarizes results for the various reaches leading to the following range of values:

Bed Widths = 2.1 m to 10.7 m

Side Slope = 4.5H:IV

Flow Depth = 1.10 m to 2.44 m

Channel Slope = 0.00031 to 0.0010

Design Velocity = 0.63 m/s to 0.83 m/S

Floods greater than the 5 year event would leave the channel and temporarily flood adjacent farmlands. However, the greater conveyance capacity of the new channels would facilitate drainage once the peaks have passed. Since total channelization would have reduced sinuosity from about 1.6 to 1.1, fewer more strategic cutoffs were incroporated with the expectation that some maintenance to retard future thalweg sinuosity within the channel would be required. Design considerations suggest that the channel in the long term will tend towards widening by attacking its banks and siltation of the bed. So far, such tendencies are not evident.

Earthwork activities adjacent to the channel salvaged the topsoil, permitted wasting of excavated material and subsequent reclamation of lands for agriculture. Due attention would be given to local inflows along the channels. The year of construction and extent of channel improvements are indicated on Figure 4.

Grade Control Structures

Given the topography of the land and the desire to obtain a relatively stable channel section, a total of 16 low drop grade control structures were designed and placed at appropriate locations along the creek channels.

Gabion type construction was favoured largely because of the soils and foundations in the project area. Flexibility, absence of positive cutoffs, ease of winter construction and economy are their main attributes. The Department pioneered the design of gabion drop structures during the last decade and has designed and constructed over 100 such structures in northwest Alberta. The basic design has been subjected to extensive hydraulic model testing (10) to establish performance parameters. Furthermore, post construction inspections and field measurements led to modifications and improvemnts. This on-going evaluation has comfirmed their satisfactory performance.

A typical Stepped Gabion Drop Structure is shown in Figure 5. The structure is built with rockfilled gabion baskets arranged on a IV:6H stepped slope with an impact block near the lower end to dissipate excess energy. The crest minimizes drawdown and counteracts convergence induced by the trapezoidal section. The structure width is governed by the need to keep the unit discharge below 2.0 $m^3/s/m$ to ensure optimum hydraulic performance. A total of five such structures were designed, all located in the lower reaches where flows were greatest.

The remaining grade control structures in the upper reaches of the creeks are Vertical Drop Gabion Structures. A typical configuration is depicted in Figure 6. This structure is somewhat less expensive than the stepped type and closely resembles a conventional vertical drop structure (11, 13, 17), except for the trapezoidal cross section and the use of gabions as the basic building block. The crest minimizes upstream drawdown, while in the basin excess energy is dissipated in a conventional hydraulic jump. Both these types of gabion are now standard designs routinely used by the department. Details of applications and specific design criteria have been described in previous paper (8), which may be consulted. Table 2 summarizes structure details and Figure 4 gives their locations.

The Namepi-Kennedy project contributed to the extension of the basic design features of the gabion drop structures in several ways. From a technical perspective the significance of high tailwater levels and its impact on hydraulic performance is more fully recognized. Innovations included the incorporation of CSP drains through the crest section to lower upstream water levels thereby minimizing ice loads. Concrete capping of upstream and upper exposed gabion surfaces was done to protect the gabion wires against abrasion and corrosion thereby ensuring structure longevity. Similarly "island type construction" has been used to protect the structure against flow exceeding the 1:5 year event. This is achieved by constructing berms on each side of the structure and using natural depressions or oxbows to by-pass flood flows.

Bridges

Results of an extensive backwater analysis for 31 bridges and crossings using the channel design parameters and grade lines were conveyed to Alberta Transportation for assessment. Alberta Transportation designed appropriate modifications and provided cost estimates based on this information. Funding was negotiated between the two departments, resulting in equal sharing of costs. In this manner a need for eleven new bridges and modification of six existing bridges was established.

Utilities and Other Improvements

Design information was conveyed to the owner of the utility to design and costs required modifications. A total of six gas pipelines had to be lowered. Such local works as channel crossings required by individual farmers were designed by the department in close consultation with the landowner to ensure functional objectives were met. Funding was by the department on the basis of actual cost of replacing an existing crossing.

CONSTRUCTION PROGRAM

Construction began on Phase I in 1977-78 and steadily progressed upstream to Phase II on Namepi Creek and Phase III on Kennedy Creek with both nearing completion in the current fiscal year, 1984-85. (6) The years of construction for the various reaches are indicated on Figure 4.

At the end of the current construction season approximately 80 km of channel improvements, construction of 16 grade control structures, 11 new bridges and remedial works on 6 others will have been completed. The work was generally done in the period from June 1 to December 15, thereby minimizing water related problems and taking advantage of frost penetration to support construction equipment.

Channel Improvements

Channel improvement work done on a hourly rate using local labour and equipment consists of enlarging and straightening of the creeks and shaping and reclaiming adjacent lands. Initial work generally consists of brush removal and stripping of the construction right of way using a cat and dozer. Excavation was done by dragline, with 1.5 to 2.0 cubic metre buckets. An initial attempt in 1977 to do cutoff excavation by motor scraper proved ineffective and was abandoned owing to the high water table and soft soil conditions.

The excavated material was deposited adjacent to the channel and levelled over a distance of 30 m on each side of the channel or wasted in the old channel and other depressions. Subsequently, the previously stripped topsoil is spread over these levelled spoil areas. This sequence proved relatively costly and time consuming. However, the landowners were quite receptive to this reclamation procedure which allowed them to put additional land to agricultural use. Typically final grading and shaping was done during the following year. It was also found to be advantageous to dig a pilot channel for prior drainage of the reach to be channelized the next year.

Figure 7, taken form the "As-Built" drawings, shows Phase I channel parameters, gradelines and the location of the lower two grade control structures.

Grade Control Structures

An average of two structures were constructed each year. All construction was done by contractors obtained by the department through public tenders, the exception being the first two structures built during 1977-78. These contractors were retained under negotiated service agreements. Most structures were placed in an off-channel location for ease of construction and to minimize care of water.

Concrete capping of the first three structures was done under service agreements after several years of operation. Cleaning and removal of debris from gabion baskets in preparation for concreting proved time consuming and costly. Consequently, the the remaining structures in succeeding years were concrete capped at the time of construction as an intergral part of the contract package. Figure 8, taken from the "As-Built" drawings, show a half-section and centreline profile of the three largest stepped gabion drop structures, NK1, NK2 and NK3. Figure 9 was prepared from the "As-Built" drawing Vertical Gabion Drop Structure K5.

Utilities and Other Improvemnts

All work on utilities was done by the owners at the request of the department. Farm crossings and similar works were constructed in accordance with the design prepared by the department in concert with the channelization program.

ECONOMIC ASPECTS

Construction Costs

The 8 year implementation program of the Namepi-Kennedy Drainage Project has a cost of about $8 million. Annual expenditures ranged from a low of about $600,000 during the first year (1977-78) to a high of just over $2.0 million during 1982-83, representing 7% and 26% of the project cost respectively.

Earthwork was by far the most costly item. While excavation accounted for 26%, the related brushing, stripping, levelling of spoil banks and reclamation of adjacent lands required 43% of the funds. Drop structures, bridges and utilities consumed 18%, 3% and 2% resepctively. Miscellaneous costs associated with such items as damage claims by farmers and labour accounted for the remaining 8%. The relative expenditures during each year and the relative contributions of the componet works expressed as percentages of the project cost are depicted in Figure 10.

Benefit Cost Relationship

An economic study conducted in 1970 by Alberta Agriculture (3) after the 1969 engineering study computed benefit/cost ratios ranging from 0.34 to 0.55 for various scenarios. A 1976 update (4) by Alberta Environment of this earlier investigation led to a benefit/cost ratio of 0.27 for primary benefits and 0.82 for both primary and secondary benefits. In 1981 departmental staff again reevaluated the benefit/cost relationship (5) concluding that the benefit/cost ratio for primary benefits would be about 0.23. Furthermore the ultimate drainage benefit assuming removal of all water related constraints throughout the basin would be about $12 million considering both direct and indirect benefits. However, the degree to which and when such benefits will accure to the project has not been definitively established. All these studies assigned a 30 year project life and considered discount rates ranging from 5% to 10%.

These economic assessments pose questions as to how well and when these benefits may be realized. Nonetheless, this economic indicator sugggests that the project would not be considered economic in the classical sense from the economic perspective. The benefit/cost ratios determined appear to be of the same order of magnitude as those for similar drainage projects. In any event the application of this ratio as a decision making tool relative to drainage and flood control projects does not enjoy universal acceptance.

CONCLUSIONS

1. Phasing a project over several seasons consistent with budgetary provisions, offers opportunities to work closely with affected landowners to achieve compatible channel improvements which enhance agricultural production.

2. Hiring local operators and equipment to do channel improvements,under direct departmental supervision requires less stringent survey control and soils information and offers greater flexibility to make field adjustments to meet functional and quality objectives.

3. The grade control structures can be conveniently and cost-effectively tendered without adversely impacting on other components of the work in progress.

4. The upgrading and modifying of bridges and utilities can be readily accomplished through the owners provided careful co-ordination and integration of activities and schedules is ensured.

5. Acquisition of easements and construction right of ways can most effectively be done by the local authority working directly with the landowners.

6. The design of gabion control structures for this project led to several innovations in their design and application, leading to economic structures.

7. The use of excavated material to fill the old channel, and subsequent landscaping and topsoiling of areas adjacent to the channel is attractive to the land owners as it immediately permits additional agricultural use.

8. The implementation of the Namepi-Kennedy Drainage project has already reduced flooding in the basin and led to improved agricultural use of previously flooded lands.

ACKNOWLEDGEMENT

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REFERENCES

(1) Agostini, R., Bizzarri, A., and Mossetti, M. (1981): Flexible structures in river and stream training works, S.p.A. OFFICINE MACCAFERRI, Bologna, Italy.

(2) Alberta Environment; 1976: Namepi Creek and Kennedy Creek Improvements, Level I Report. PYD Engineering, D12660.

(3) Alberta Agriculture, 1970: The Namepi-Kennedy Creek Project, An Economic Feasibility Study.

(4) Alberta Environment, 1976: Namepi-Kennedy Creeks Flood Control, Economic Impact Assessment.

(5) Alberta Environment, 1981: An Economic Study of the Namepi-Kennedy Drainage Project.

(6) Alberta Environment, 1982: Construction Report No. 1, Namepi-Kennedy Project, 1977-78 to 1981-82. (Draft Report).

(7) Environment Conservation Authority, 1976: Erosion of Land in Northwestern Alberta, Report and Recommendations.

(8) Lindner, D. H. 1983: Application and Design Practise of Gabion Drop Structures in Alberta, Canadian Society for Civil Engineering. Proceedings of 6th Canadian Hydrotechnical Conference, Ottawa, Vol I, p.55.

(9) Maccaferri Gabions of Canada Ltd., 1977: The Use of Gabions in Flood Control, Technical Booklet No. 1.

(10) Mah, J., 1981: Hydraulic Model Studies of Berwyn Stepped Drop, University of Alberta, Faculty of Graduate Studies, M. Eng. Thesis.

(11) Peterka, A. J., 1964: Hydraulic Design of Stilling Basins and Energy Dissipators, U.S. Bureau of Reclamation, Engineering Monograph No. 25.

(12) Roads and Transportation, 1982: Drainage Manual, Vol. I.

(13) Smith, C.D. 1978: Hydraulic Structures, University of Saskatchewan.

(14) Stephenson, D., 1979: Gabion Energy Dissipators, Interntional Commission on Large Dams, Congress New Delhi, Q50, R3, p.33.

(15) United States Bureau of Reclamation, 1974: Design of Small Canal Structures, Denver, Colorado.

(16) United States Corps of Engineers, 1970. Hydraulic Design of Flood Control Channels, EM 1110-2-1601.

(17) United States Department of Agriculture, Soils Conservation Service, Engineering Handbook, Drop Spillways, Section 11.

(18) United States Department of Agriculture, Soils Conversation Service, 1973: Drainage of Agricultural Land.

(19) University of Alberta Press, 1969: Atlas of Alberta.

TABLE 1

NAMEPI-KENNEDY DRAINAGE PROJECT

CHANNEL PARAMETERS

Phase	Design Flow (m^3/s)	Bed Width (m)	(1) Normal Depth (m)	Bed Slope	Design Velocity (m/s)
I	36.1	10.7	2.44	0.00031	0.69
II	24.3	6.1	2.17	0.00031	0.71
	24.3	8.0	1.83	0.00048	0.82
	18.2	6.9	1.56	0.00060	0.83
	18.2	6.8	1.67	0.00048	0.77
	10.8	4.8	1.40	0.00051	0.69
	6.2	3.1	1.10	0.00075	0.70
III	10.8	6.1	1.38	0.00041	0.63
	10.8	4.6	1.35	0.00065	0.76
	10.8	2.3	1.44	0.00087	0.85
	10.8	2.4	1.49	0.00070	0.79
	6.2	2.1	1.12	0.00100	0.78

NOTES: (1) All channel side slopes are 4.5:1

(2) All Manning's "n" = 0.030 except 0.035 in Phase I

TABLE 2

NAMEPI-KENNEDY DRAINAGE PROJECT

GRADE CONTROL STRUCTURE SUMMARY

Phase	Structure	Structure Type	Design Flow (m^3/s)	Drop Height (m)	Base Width (m)	Year of Construction
I	NK1	S	36.1	1.4	17.4	1977
	NK2	S	36.1	1.4	17.4	1978
	NK3	S	36.1	1.4	17.4	1979
II	N4	C	24.3	2.8	9.0	1980-81
	N5	S	24.3	1.4	17.4	1979-80
	N6	V	24.3	1.0	11.0	1980-81
	N7	V	24.3	1.5	11.0	1982-83
	N8	V	24.3	1.0	11.0	1982-83
	N9	V	18.2	1.0	8.0	1982-83
	N10	V	10.8	1.5	5.0	1983-84
	N11	V	6.2	1.0	6.0	1983-84
III	K1	S	10.8	1.8	8.2	1979-80
	K2	V	10.8	1.0	5.0	1980-81
	K3	V	10.8	1.0	5.0	1982-83
	K4	V	10.8	1.0	5.0	1982-83
	K5	V	6.2	1.0	3.0	1982-83

C = Concrete Chute Drop Structure
S = Stepped Gabion Drop Structure
V = Vertical Gabion Drop Structure

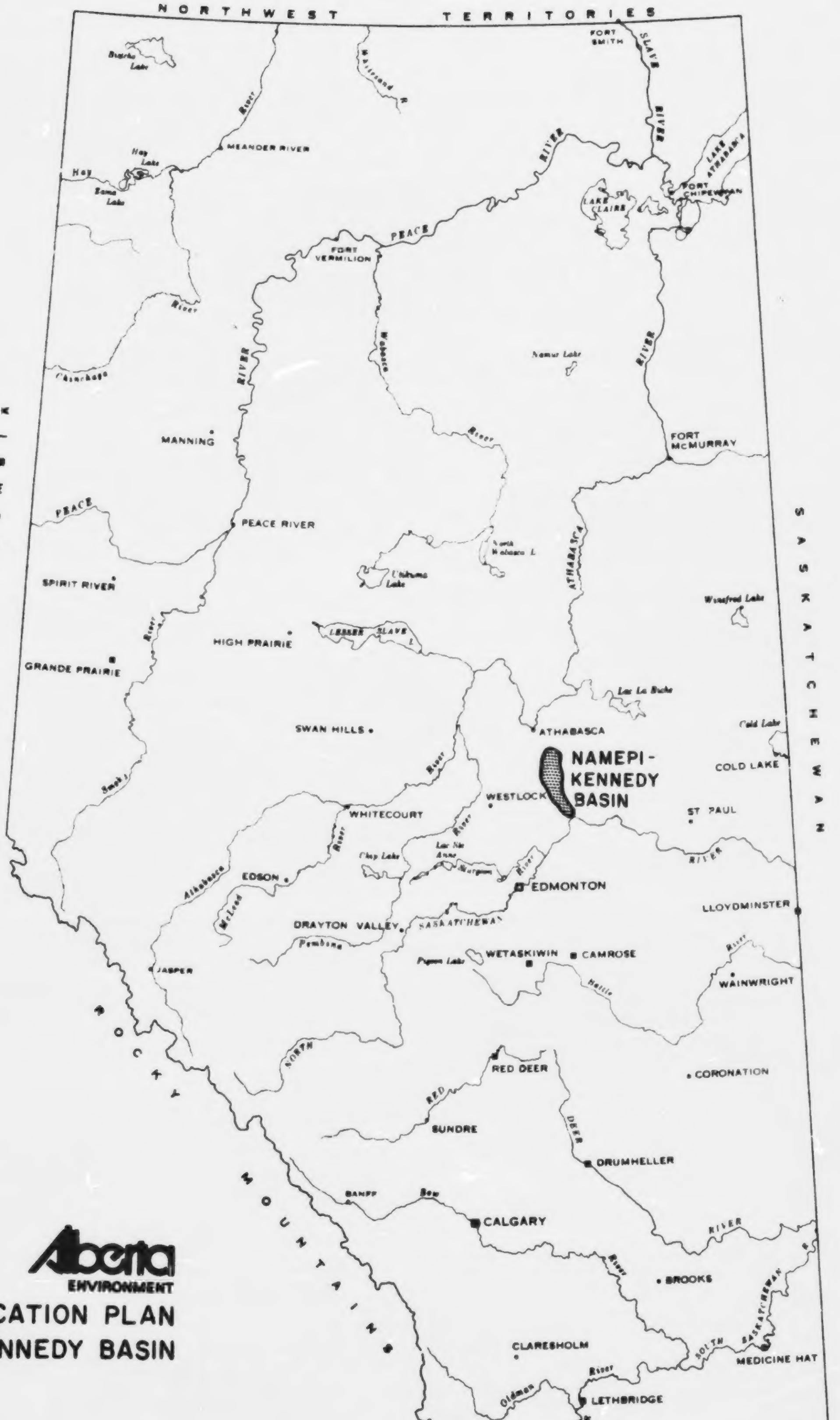

NORTHWEST TERRITORIES
FORT SMITH
SLAVE RIVER
LAKE ATHABASCA
FORT CHIPEWYAN
LAKE CLAIRE
MEANDER RIVER
Hay Lake
River
PEACE
FORT VERMILION
RIVER
Namur Lake
MANNING
FORT McMURRAY
PEACE
PEACE RIVER
SPIRIT RIVER
North Wabasca L.
ATHABASCA
Utikuma Lake
Winefred Lake
HIGH PRAIRIE
LESSER SLAVE L
GRANDE PRAIRIE
Lac La Biche
SWAN HILLS
ATHABASCA
Cold Lake
COLD LAKE
NAMEPI-KENNEDY BASIN
WESTLOCK
ST PAUL
WHITECOURT
EDSON
EDMONTON
LLOYDMINSTER
DRAYTON VALLEY
SASKATCHEWAN
WETASKIWIN
CAMROSE
Pigeon Lake
JASPER
WAINWRIGHT
RED DEER
CORONATION
SUNDRE
DRUMHELLER
BANFF
Bow
CALGARY
RIVER
BROOKS
CLARESHOLM
SOUTH SASKATCHEWAN
MEDICINE HAT
Oldman River
LETHBRIDGE
St. Mary Res
Pakowki Lake
CARDSTON
MONTANA
BRITISH COLUMBIA
ROCKY MOUNTAINS
SASKATCHEWAN

FIGURE 1.

Alberta
ENVIRONMENT

LOCATION PLAN
NAMEPI-KENNEDY BASIN

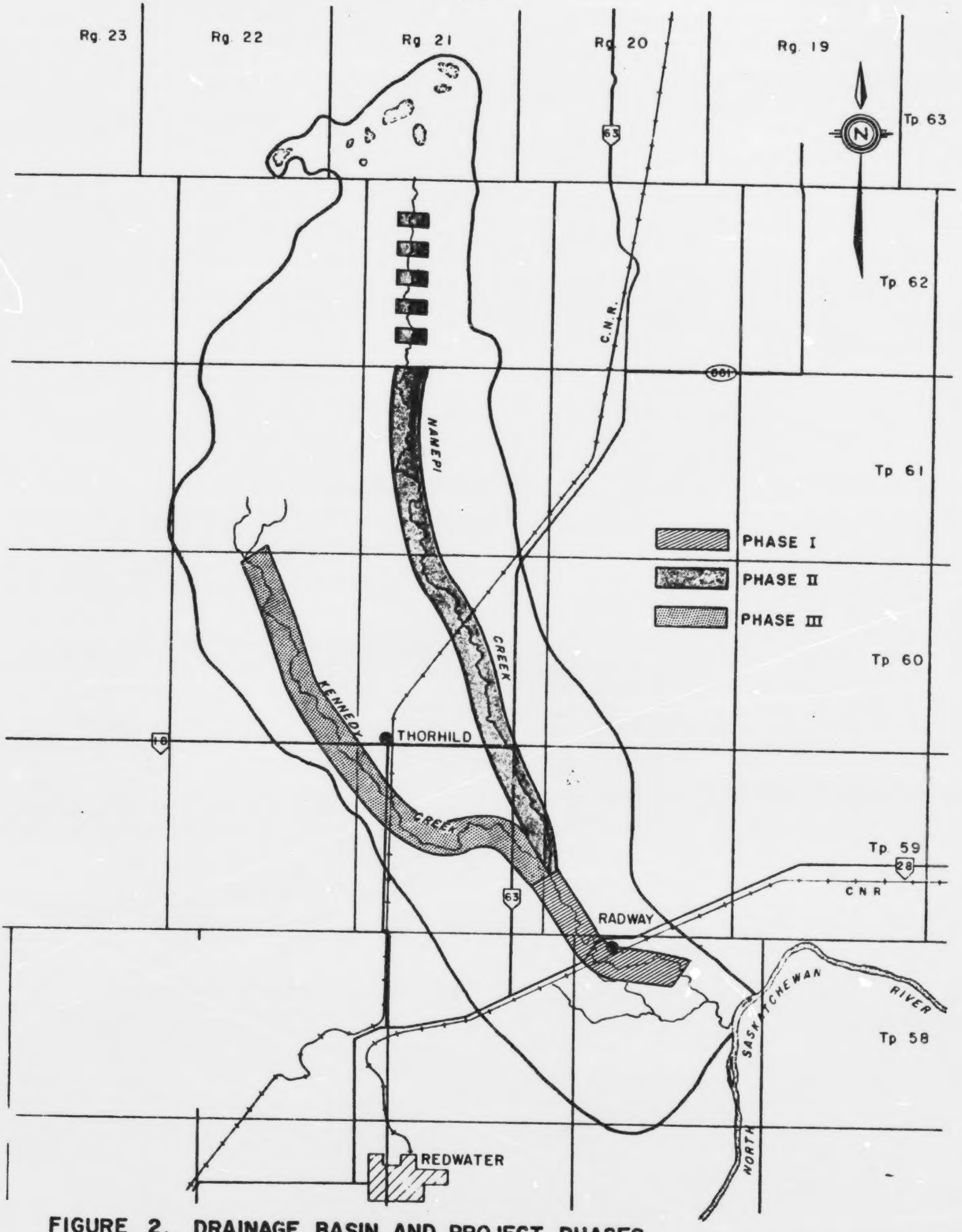

Rg. 23
Rg. 22
Rg. 21
Rg. 20
Rg. 19
Tp 63
Tp. 62
Tp. 61
Tp. 60
Tp. 59
Tp. 58
N
63
C.N.R.
661
NANEPI
CREEK
KENNEDY
CREEK
PHASE I
PHASE II
PHASE III
18
THORHILD
63
28
CNR
RADWAY
SASKATCHEWAN
RIVER
NORTH
REDWATER

FIGURE 2. DRAINAGE BASIN AND PROJECT PHASES.

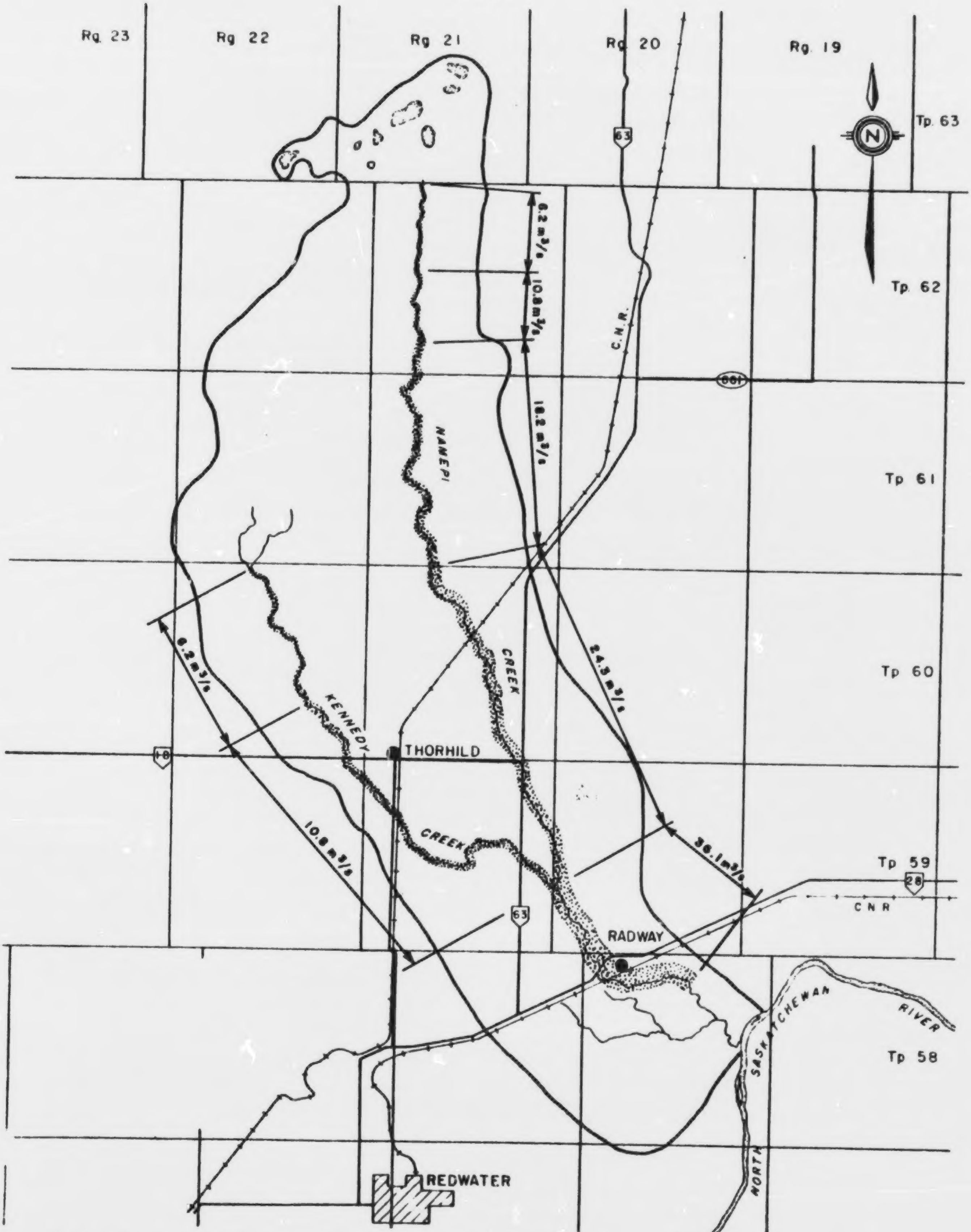

Rg. 23
Rg. 22
Rg. 21
Rg. 20
Rg. 19
N
Tp. 63
Tp. 62
Tp 61
Tp 60
Tp 59
Tp 58
63
661
28
18
63
C.N.R.
CNR
6.2 m^3/s
10.8 m^3/s
18.2 m^3/s
24.3 m^3/s
36.1 m^3/s
6.2 m^3/s
10.8 m^3/s
NAMEPI
CREEK
KENNEDY
CREEK
THORHILD
RADWAY
REDWATER
NORTH SASKATCHEWAN RIVER

FIGURE 3. DESIGN FLOWS (1:5 YEAR EVENT).

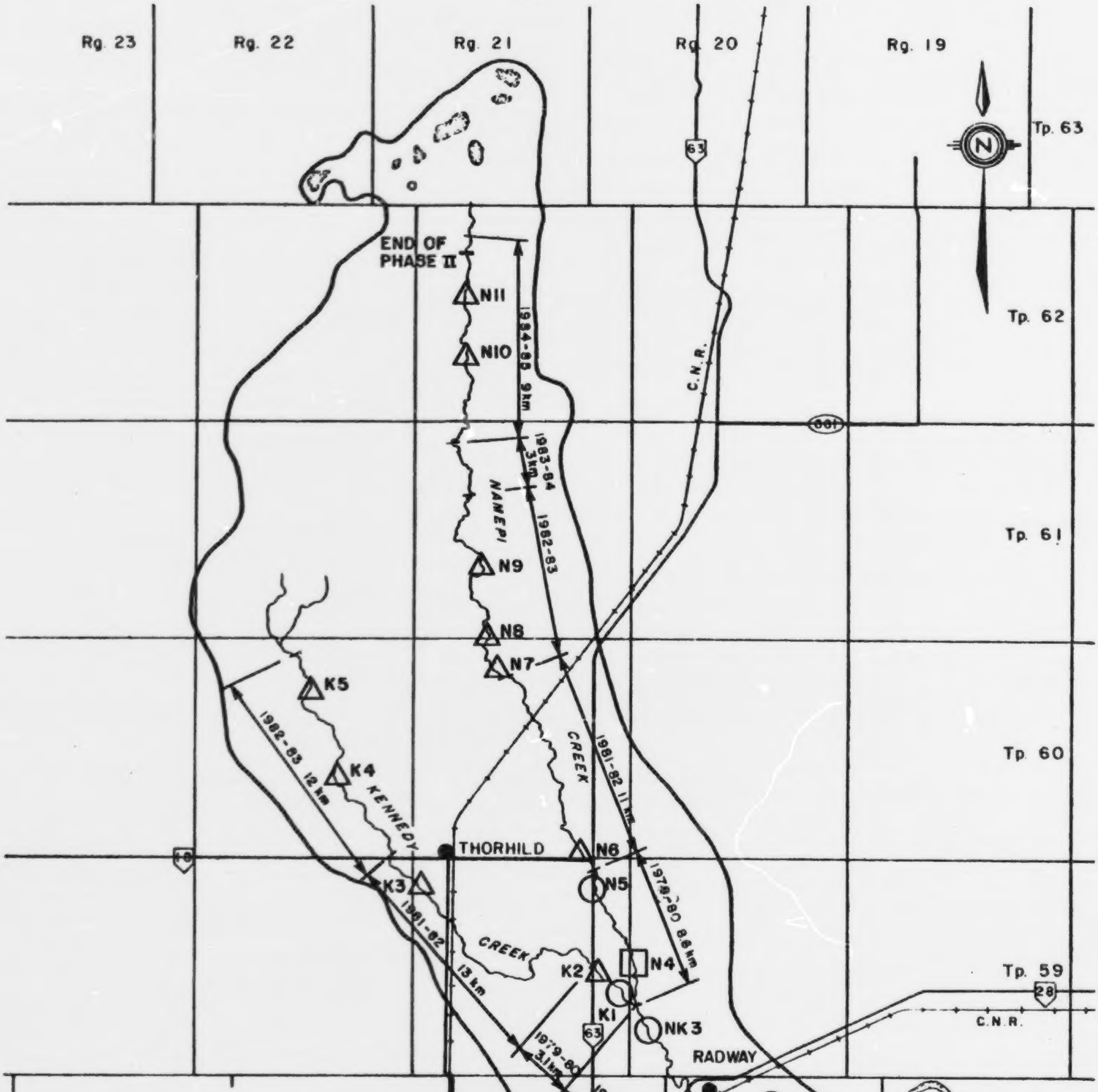
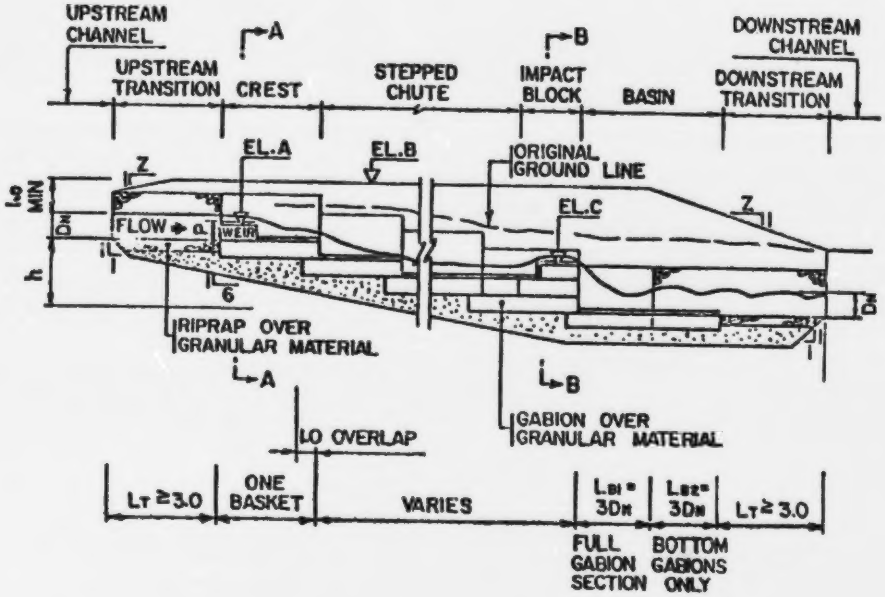
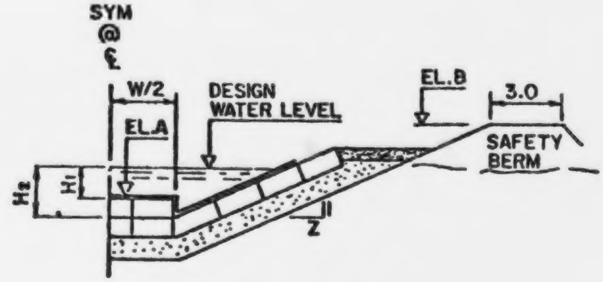
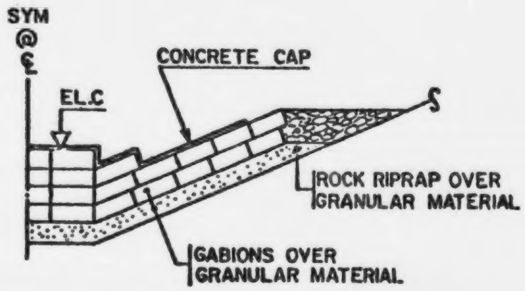

Rg. 23
Rg. 22
Rg. 21
Rg. 20
Rg. 19
N
Tp. 63
Tp. 62
Tp. 61
Tp. 60
Tp. 59
Tp. 58
63
661
18
28
C.N.R.
C.N.R.
END OF PHASE II
N11
N10
1984-85 9 km
1983-84 3 km
NANEPI
1982-83
N9
N8
N7
CREEK
1981-82 11 km
K5
1982-83 12 km
K4
KENNEDY
THORHILD
N6
K3
N5
1979-80 8.8 km
1981-82 13 km
CREEK
K2
N4
K1
NK3
1979-80 3.1 km
1978-79 7.9 km
RADWAY
NK2
NK1
1977-78 3.2 km
NORTH SASKATCHEWAN RIVER
REDWATER

FIGURE 4. CHANNEL IMPROVEMENTS AND STRUCTURE LOCATIONS.


UPSTREAM CHANNEL
UPSTREAM TRANSITION
CREST
A
STEPPED CHUTE
B
IMPACT BLOCK
BASIN
DOWNSTREAM CHANNEL
DOWNSTREAM TRANSITION
EL.A
EL.B
ORIGINAL GROUND LINE
EL.C
Z
1
Lo MIN
DN
h
FLOW ➔ a
WEIR
6
RIPRAP OVER GRANULAR MATERIAL
GABION OVER GRANULAR MATERIAL
LO OVERLAP
LT ≥ 3.0
ONE BASKET
VARIES
LB1 = 3DN
LB2 = 3DN
LT ≥ 3.0
FULL GABION SECTION
BOTTOM GABIONS ONLY

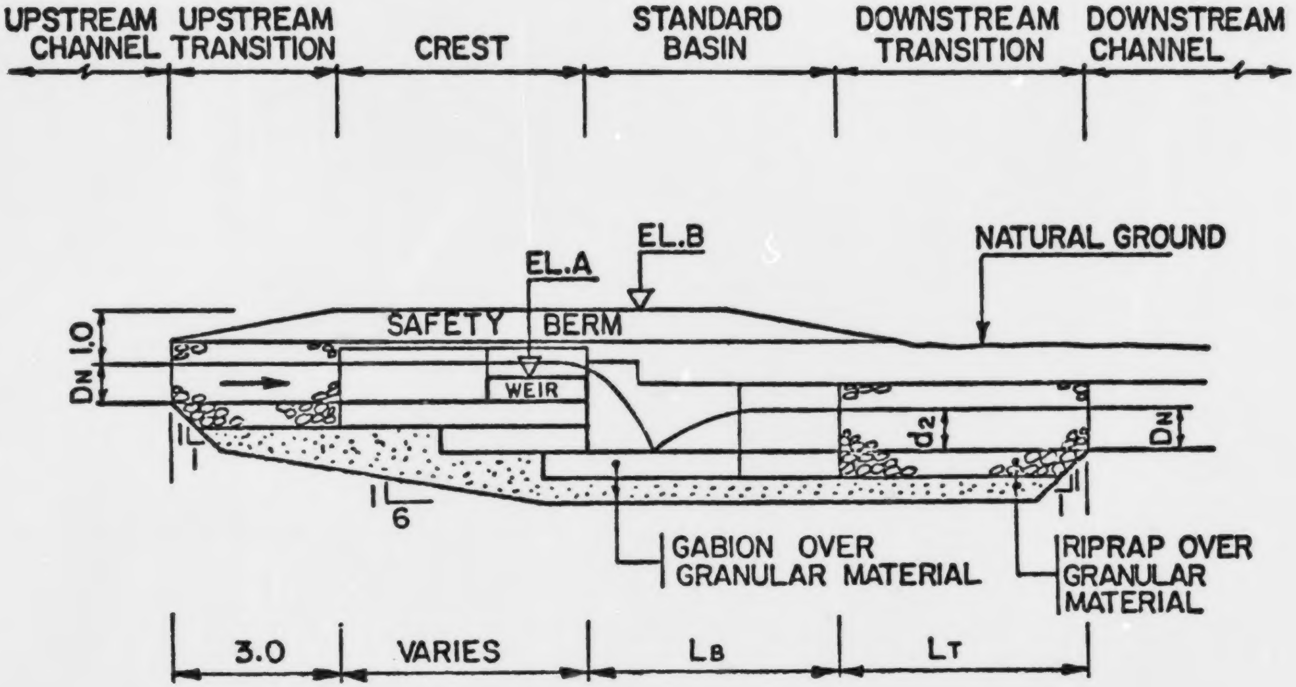

SYM @ ℄
W/2
DESIGN WATER LEVEL
EL.B
3.0
EL.A
SAFETY BERM
H2
H1
Z
1

HALF-SECTION A-A


SYM @ ℄
CONCRETE CAP
EL.C
ROCK RIPRAP OVER GRANULAR MATERIAL
GABIONS OVER GRANULAR MATERIAL

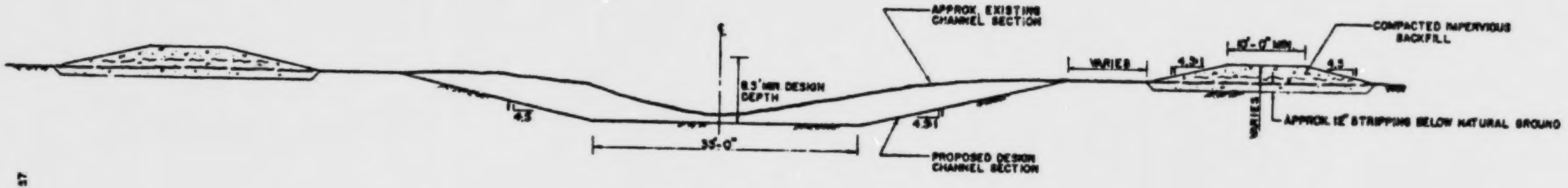
HALF-SECTION B-B

FIGURE 5. TYPICAL STEPPED GABION DROP STRUCTURE CROSS-SECTIONS.

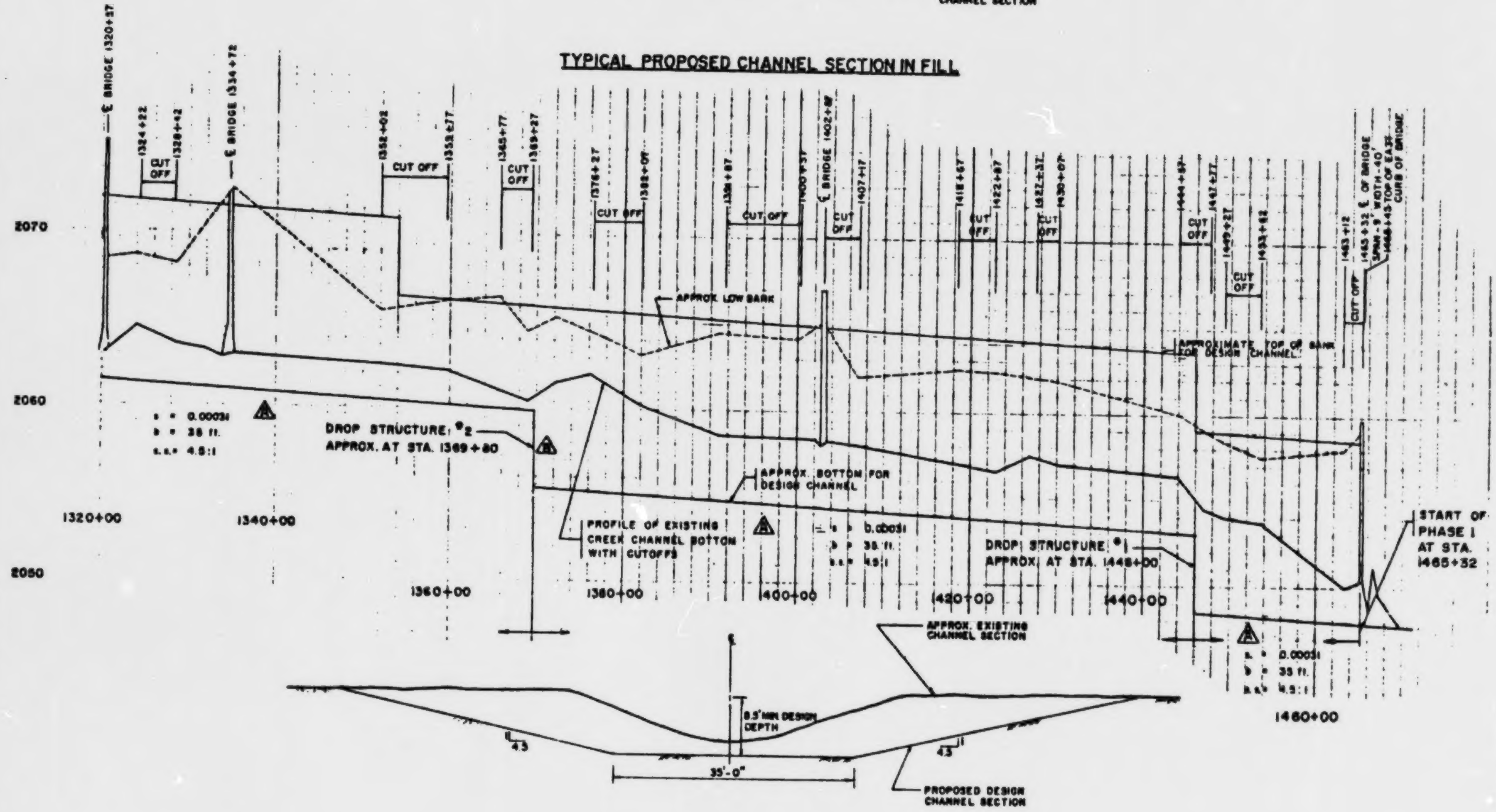

UPSTREAM CHANNEL
UPSTREAM TRANSITION
CREST
STANDARD BASIN
DOWNSTREAM TRANSITION
DOWNSTREAM CHANNEL
EL.B
EL.A
NATURAL GROUND
SAFETY BERM
WEIR
1.0
DN
d2
DN
1
1
1
6
1
1
GABION OVER GRANULAR MATERIAL
RIPRAP OVER GRANULAR MATERIAL
3.0
VARIES
LB
LT

℄ - PROFILE

FIGURE 6. TYPICAL VERTICAL GABION DROP STRUCTURE.


APPROX. EXISTING CHANNEL SECTION
COMPACTED IMPERVIOUS BACKFILL
VARIES
4.5:1
10'-0" MIN.
4.5
8.5' MIN DESIGN DEPTH
4.3
4.5:1
35'-0"
VARIES
APPROX. 12" STRIPPING BELOW NATURAL GROUND
PROPOSED DESIGN CHANNEL SECTION

TYPICAL PROPOSED CHANNEL SECTION IN FILL


2070
2060
2050
℄ BRIDGE 1320+37
1324+22
CUT OFF
1328+42
℄ BRIDGE 1334+72
1352+02
CUT OFF
1353+77
1365+77
CUT OFF
1369+27
1376+27
CUT OFF
1382+07
1391+87
CUT OFF
1400+57
℄ BRIDGE 1402+87
CUT OFF
1407+17
1418+67
CUT OFF
1422+87
1427+37
CUT OFF
1430+07
1444+57
CUT OFF
1447+77
1449+27
CUT OFF
1453+62
1463+12
CUT OFF
1465+32 ℄ OF BRIDGE
SPAN-9' WIDTH-40'
1466+45 TOP OF EAST CURB OF BRIDGE
APPROX. LOW BANK
APPROXIMATE TOP OF BANK FOR DESIGN CHANNEL
s = 0.00031
b = 35 ft.
s.s. = 4.5:1
DROP STRUCTURE #2 APPROX. AT STA. 1369+80
APPROX. BOTTOM FOR DESIGN CHANNEL
PROFILE OF EXISTING CREEK CHANNEL BOTTOM WITH CUTOFFS
s = 0.00031
b = 35 ft.
s.s. = 4.5:1
DROP STRUCTURE #1 APPROX. AT STA. 1448+00
START OF PHASE I AT STA. 1465+32
1320+00
1340+00
1360+00
1380+00
1400+00
1420+00
1440+00
1460+00
s = 0.00031
b = 35 ft.
s.s. = 4.5:1
APPROX. EXISTING CHANNEL SECTION
8.5' MIN DESIGN DEPTH
4.3
4.3
35'-0"
PROPOSED DESIGN CHANNEL SECTION

TYPICAL PROPOSED CHANNEL SECTION IN CUT

FIGURE 7. PHASE I PROFILE AND TYPICAL CROSS-SECTIONS

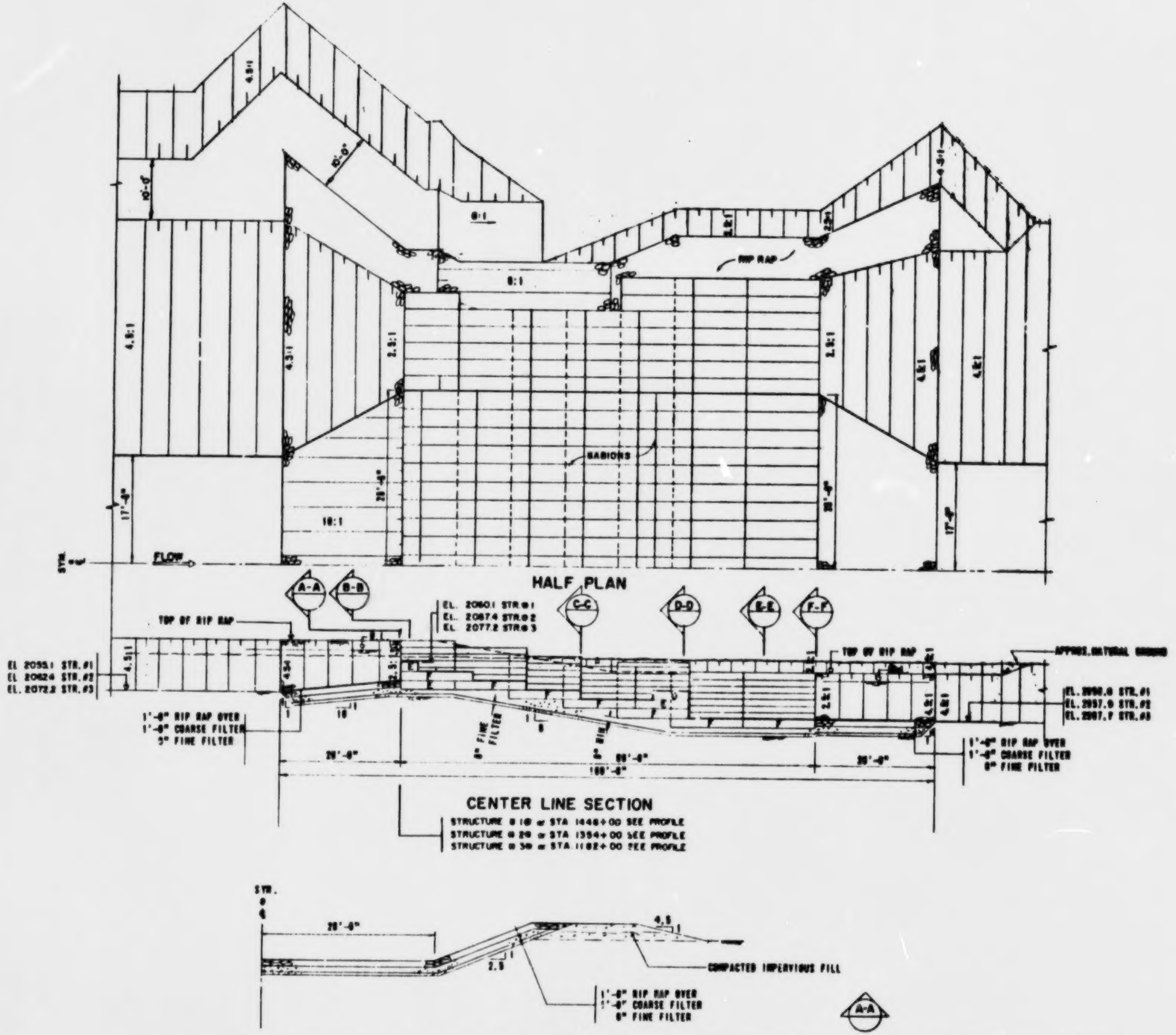
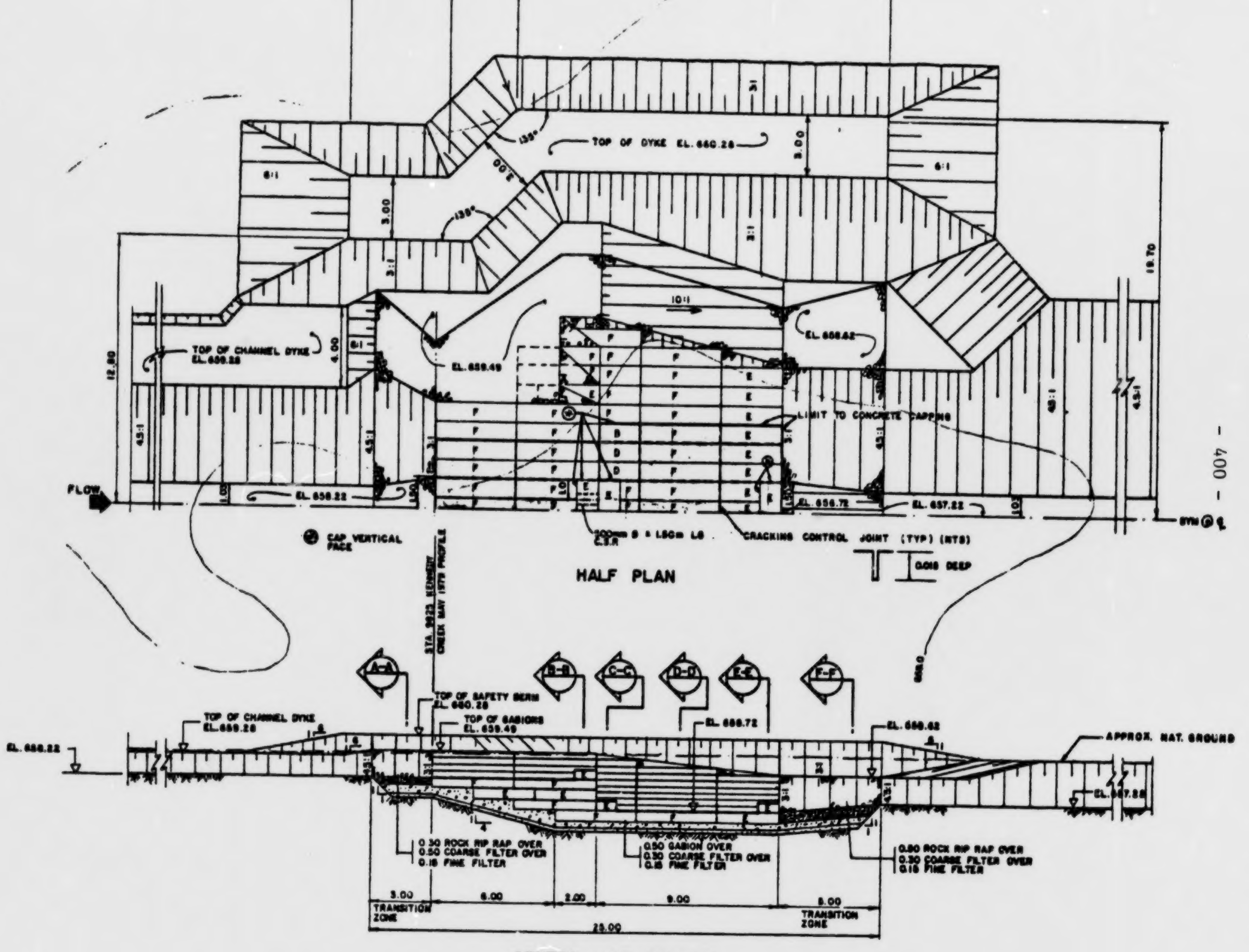

4.5:1
10'-0"
10'-0"
8:1
8:1
2.5:1
2.5:1
RIP RAP
4.5:1
4.5:1
2.5:1
2.5:1
4.5:1
4.5:1
GABIONS
17'-0"
20'-0"
10:1
20'-0"
17'-0"
SYM.
FLOW
HALF PLAN
A-A
B-B
C-C
D-D
E-E
F-F
TOP OF RIP RAP
EL. 2060.1 STR.#1
EL. 2067.4 STR.#2
EL. 2077.2 STR.#3
TOP OF RIP RAP
APPROX. NATURAL GROUND
EL 2055.1 STR.#1
EL 2062.4 STR.#2
EL. 2072.2 STR.#3
4.5:1
1'-0" RIP RAP OVER
1'-0" COARSE FILTER
3" FINE FILTER
10
1
8" FINE FILTER
8
1
20'-0"
80'-0"
160'-0"
20'-0"
2.5:1
4.5:1
EL. 2050.0 STR.#1
EL. 2057.9 STR.#2
EL. 2067.7 STR.#3
1'-0" RIP RAP OVER
1'-0" COARSE FILTER
8" FINE FILTER
CENTER LINE SECTION
STRUCTURE # 1 @ STA 1446+00 SEE PROFILE
STRUCTURE # 2 @ STA 1354+00 SEE PROFILE
STRUCTURE # 3 @ STA 1182+00 SEE PROFILE
SYM.
20'-0"
4.5
1
2.5
1
COMPACTED IMPERVIOUS FILL
1'-0" RIP RAP OVER
1'-0" COARSE FILTER
8" FINE FILTER
A-A

FIGURE 8. HALF-PLAN AND PROFILE STEEPED GABION DROPS NK1, NK2, & NK3.


4.35
3.85
18.10
TOP OF DYKE EL. 660.28
135°
3.00
6:1
3:1
10:1
19.70
12.80
4.00
TOP OF CHANNEL DYKE EL. 659.28
EL. 659.49
EL. 658.62
LIMIT TO CONCRETE CAPPING
4.5:1
F
D
E
FLOW
EL. 656.22
EL. 656.72
EL. 657.22
SYM @ ℄
CAP VERTICAL FACE
STA. 9923 KENNEDY CREEK MAY 1979 PROFILE
200mm ∅ × 1.50m LG C.S.R.
CRACKING CONTROL JOINT (TYP) (NTS)
0.018 DEEP
HALF PLAN
A-A
B-B
C-C
D-D
E-E
F-F
TOP OF SAFETY BERM EL. 660.28
TOP OF CHANNEL DYKE EL. 659.28
TOP OF GABIONS EL. 659.49
EL. 656.72
EL. 658.62
EL. 656.22
APPROX. NAT. GROUND
EL. 657.22
0.30 ROCK RIP RAP OVER
0.50 COARSE FILTER OVER
0.15 FINE FILTER
0.50 GABION OVER
0.30 COARSE FILTER OVER
0.15 FINE FILTER
0.80 ROCK RIP RAP OVER
0.30 COARSE FILTER OVER
0.15 FINE FILTER
3.00
6.00
2.00
9.00
5.00
TRANSITION ZONE
TRANSITION ZONE
25.00

CENTER LINE SECTION

FIGURE 9. HALF-PLAN AND PROFILE OF VERTICAL DROP GABION STRUCTURE K5.

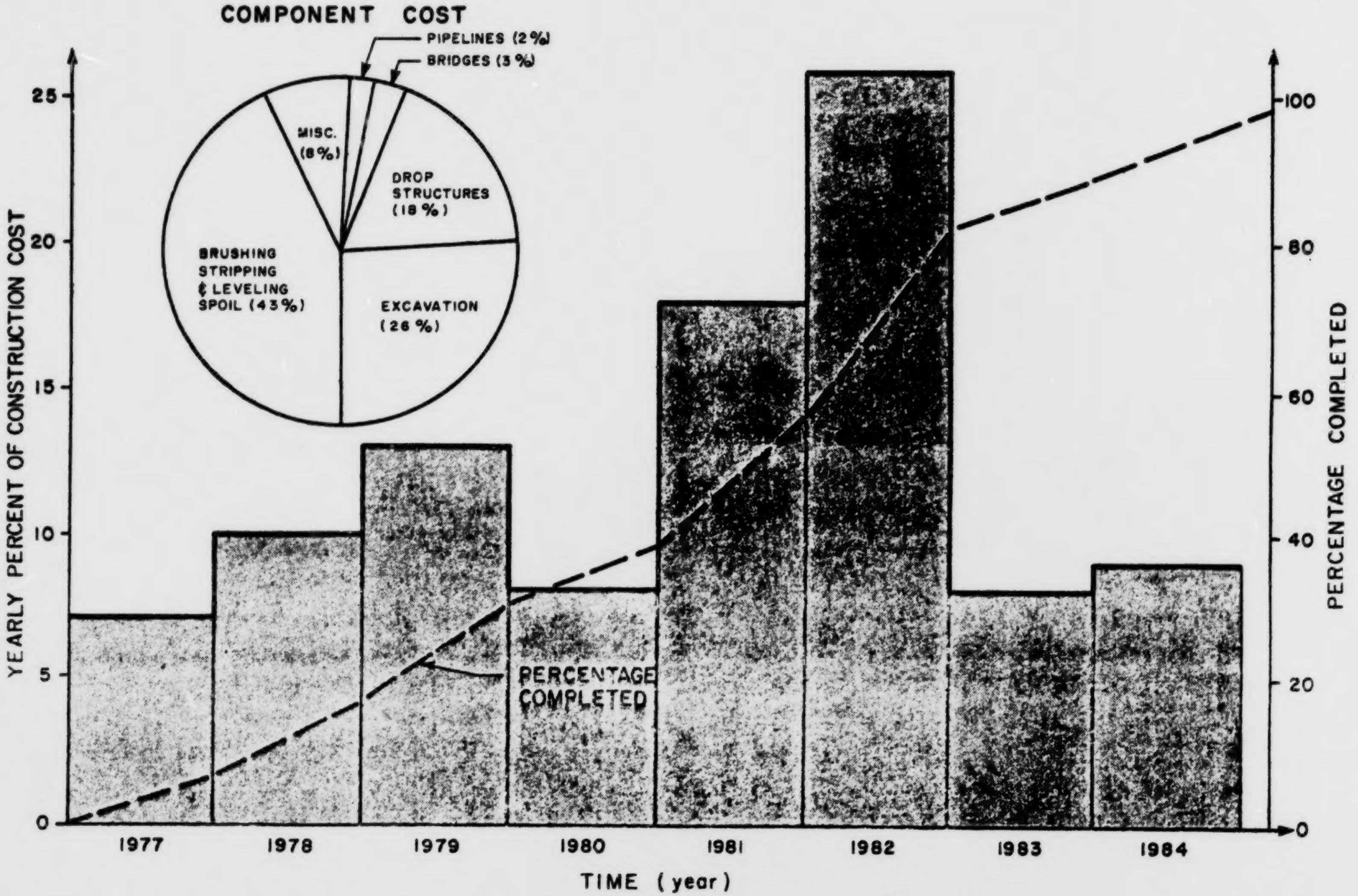


FIGURE 10. PERCENT OF EXPEDITURE PER YEAR AND FOR COMPONENTS.

SESSION IV

Drainage Impacts

Session Chairman: W. Cowan

PRIME WETLAND LAND USE MONITORING ACTIVITIES AND NEEDS IN SOUTHERN CANADA*

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ABSTRACT

The Prime Resource Lands component of the Canada Land Use Monitoring Program of Lands Directorate, Environment Canada includes a project focussing on land use change as it affects wetlands in Southern Canada. The project is composed of several studies which either use available data bases or create new data sets to provide statistics on wetland conversions. These studies are in various stages of completion.

This paper provides an overview of the Canada Land Use Monitoring Program and reviews the studies of the wetlands project. The current and recently completed studies provide: i) a synopsis of available quantitative information on wetlands conversions, ii) statistics and maps on wetland loss within urban-centred regions, and iii) regional wetland loss evaluations for the Fraser Delta, Southern Ontario, the St. Lawrence River, Montreal Region, and the Tantramar Marshes in Atlantic Canada. An additional study is aimed at assessing LANDSAT Thematic Mapper digital data interpretation methods, for wetland monitoring.

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*Paper prepared for the Third Annual Western Provincial Conference, on Rationalization of Water and Soil Research and Management, entitled Agricultural Land Drainage, November 20-22, 1984, Winnipeg, Manitoba.

INTRODUCTION

The decline and loss of wetlands has been identified as one of the major land use issues facing both federal and provincial agencies across Canada. Wetlands in Canada encompass approximately 14% of the nation's land surface covering over 1.27 million km^2 as bogs, fens, swamps, marshes and shallow water areas (National Wetland Working Group, 1984). These wetlands form a key component in the landscape, often having critical values for wildlife habitat, nutrient recycling, water and flood management, ecological conservation, recreation, and education. Many of these areas are under land use pressures such as urban development, agricultural production, and harbour construction. They also are the source of peat deposits for agricultural and energy development.

The area in Canada likely to have the most intense conflicts between wetland conservation and wetland utilization for such developments is concentrated in the south, closer to cities and productive farmlands. This roughly corresponds to the area covered by the Canada Land Inventory (CLI), the 2.4 million km^2 agricultural ecumene of southern Canada.

The need for monitoring the effects of land use changes external to and within these wetlands in southern Canada was identified early in the establishment of the Canada Land Use Monitoring Program (CLUMP) within the Lands Directorate of Environment Canada. This paper briefly outlines the general objectives of CLUMP with emphasis on its Prime Resource Lands component, including the Prime Wetlands project. The major studies which have been initiated across Canada to provide a national overview of wetland land use conversion, which are scheduled for completion by 1986, are reviewed. A discussion follows centering on the role of land use change research in the context of wetlands as a significant national resource.

CANADA LAND USE MONITORING PROGRAM

The Canada Land Use Monitoring Program (CLUMP) was initiated in 1978 in response to a federal cabinet directive to develop a program for monitoring land use change in Canada (Rump, 1983). The need for the program is based on the fundamental importance of land to the nation, particularly with respect to the economy and land use impacts of federal and provincial policies and programs, the increased scale of developments affecting land, the corresponding expansion in the intensity and intricacy of land use problems, and the lack of an existing, comprehensive national land use change monitoring program. Within this framework the objectives established for CLUMP are:

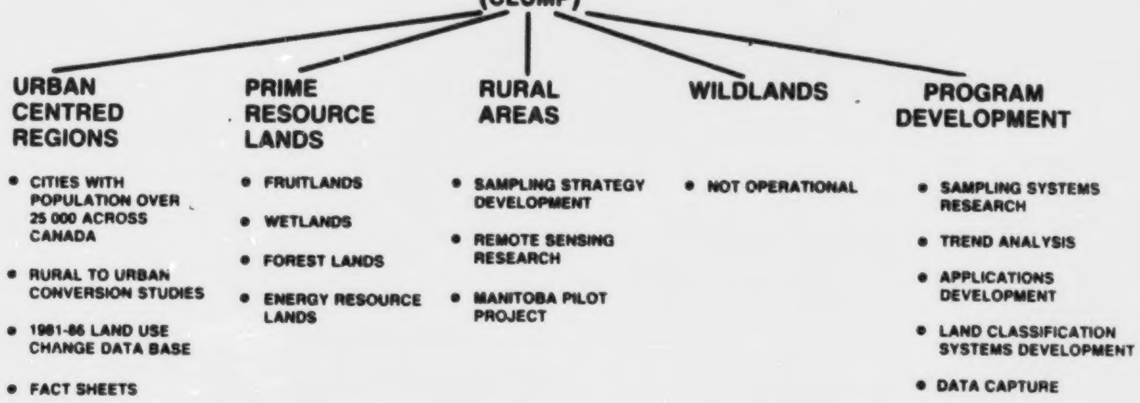
1) To monitor the amount, location, and type of land use in Canada on national and regional scales in support of the production of statistics on land use trends; and

2) to produce national and regional data sets on land use change.

The Federal Policy on Land Use was approved by Cabinet in December 1980. The Policy is designed to guide the internal activities of the federal government so that adequate consideration is given to the impact on the land resource. The CLUMP program contributes to the fulfillment of the Federal Policy on Land Use through the provision of land use change information to assist in achieving sound land resource management.

For land use monitoring in Canada, four components of CLUMP have been distinguished on the basis of geographical area, dominant land use, land use change issues, and the rate of change. These components are: Urban Centred Regions, Prime Resource Lands, Rural Areas, and Wildlands. A fifth component, as outlined in Figure 1, encompasses program development and includes studies on land use classification, remote sensing, applications, sampling strategies, and trend analysis.

FIGURE 1
CANADA LAND USE MONITORING PROGRAM (CLUMP)


URBAN CENTRED REGIONS
• CITIES WITH POPULATION OVER 25 000 ACROSS CANADA
• RURAL TO URBAN CONVERSION STUDIES
• 1981-86 LAND USE CHANGE DATA BASE
• FACT SHEETS
PRIME RESOURCE LANDS
• FRUITLANDS
• WETLANDS
• FOREST LANDS
• ENERGY RESOURCE LANDS
RURAL AREAS
• SAMPLING STRATEGY DEVELOPMENT
• REMOTE SENSING RESEARCH
• MANITOBA PILOT PROJECT
WILDLANDS
• NOT OPERATIONAL
PROGRAM DEVELOPMENT
• SAMPLING SYSTEMS RESEARCH
• TREND ANALYSIS
• APPLICATIONS DEVELOPMENT
• LAND CLASSIFICATION SYSTEMS DEVELOPMENT
• DATA CAPTURE

Urban Centred Regions: The urban centred regions (UCR) component of CLUMP, operational since 1979, provides a national perspective on land use changes in the rural-urban fringe areas adjacent to Canadian cities with over 25 000 population. Land use change data is collected on a five-year basis coincident with census years. The establishment of such a project reflects the occurrence of high quality resource lands and the relatively rapid rate of land use change in these areas. To date, the output has focussed on one type of land use change -- rural to urban land conversion. These data show the amount of land removed from existing and potential renewable resource production. Between 1976 and 1981, 19 859 ha of rural land was converted to urban uses in the eleven major Prairie urban centred regions, 65% of which was class 1-3 for agriculture. For 1981, land use base maps have been created for all urban centred regions using the CLUMP land use classification system designed specifically for monitoring purposes (Gierman, 1981). The system is comprehensive, hierarchical, and composed of two sub-classifications for land activity and land cover. We are currently preparing for the 1986 urban centred region cycle when the total range of net and dynamic land use changes will be available for analysis.

Rural Areas: The rural areas component is currently under development. The monitoring method focusses on an area sampling-remote sensing approach using a limited number of land activity and land cover classes. The objective of this component is to provide land use change statistics for the total settled area of Canada on broad regional and national scales. This summer and fall a pilot project is being conducted in the agricultural and agricultural-boreal fringe area of Manitoba to evaluate and cost a stratified two-stage sampling design using one by three mile segments. Current 1984 colour 70 mm photography of the segments is being interpreted and measured for land use. Land use change data is being obtained from 1970 LIFT photography. This pilot project is a cooperative one, involving Agriculture Canada, Statistics Canada, the Canada Centre for Remote Sensing, and Environment Canada.

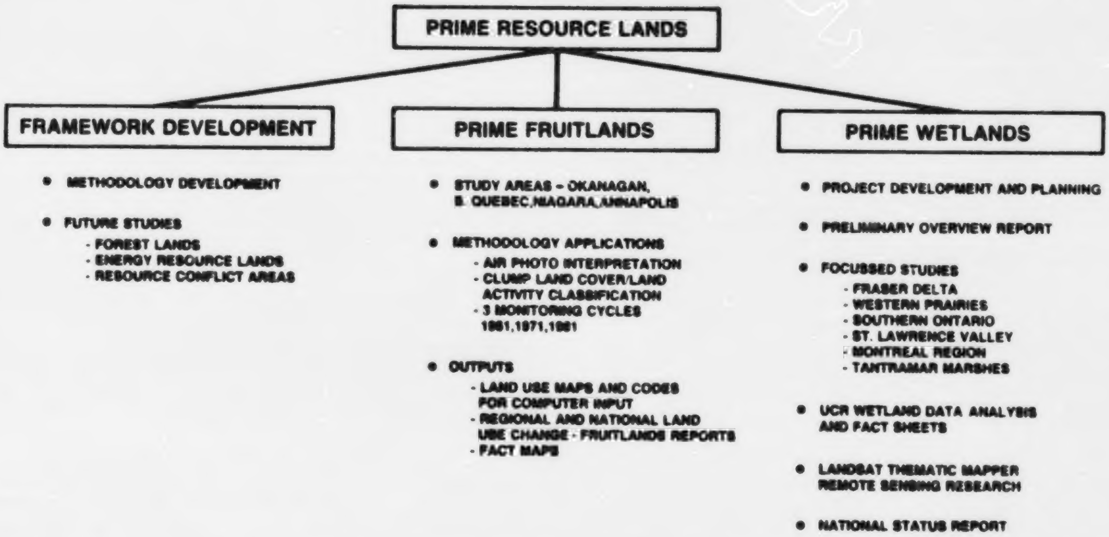
PRIME RESOURCE LANDS

This component of CLUMP was initiated in 1981. Prime resource lands can be labelled "special", "unique", or "critical" and include lands in use for agriculture, forestry, wildlife, recreation, or another renewable resource use. They are defined on the basis of their inherent physical, environmental qualities or socio-economic factors which interact on the land to allow production of goods and services essential to the economic, environmental or social well-being of Canada. Prime resource lands are relatively scarce. In addition, significant increases in the production of land-based commodities such as those forecast for forestry (a 50% increase in production by the year 2000) can only be achieved from more intensive utilization and better management of the prime lands already in use.

Nevertheless, prime resource lands often are subject to resource use conflicts from land use changes due to urban development or agricultural expansion. Conversion of prime wetlands is affected by both of these factors. Reliable information on the dynamics of land use changes on prime resource lands is important to all levels of government, the private sector, and the public in order to evaluate land use patterns and to develop appropriate programs and related policy.

The major elements of the CLUMP Prime Resource Lands component are shown in Figure 2. The initial project of the component centres on the primary fruit growing areas (Prime Fruitlands) of Canada (Seguin and Rump, 1984). Four regional data sets have been established for the Okanagan Valley, the Niagara Peninsula, the St. Lawrence Lowlands south of Montreal, and the Annapolis Valley of Nova Scotia. The spatial data base at the 1:50 000 scale consists of land activity and cover information for 1961, 1971, and 1981; agricultural capability; census boundaries; and federal properties. All data bases are entered into the Canada Land Data System, a geographic computerized map storage, analysis and retrieval system with unique overlay capabilities. The CLUMP land use classification (Gierman, 1981) was used for all four study areas making the results consistent and compatible. The

FIGURE 2
CANADA LAND USE MONITORING PROGRAM
(CLUMP)


PRIME RESOURCE LANDS
FRAMEWORK DEVELOPMENT
PRIME FRUITLANDS
PRIME WETLANDS
• METHODOLOGY DEVELOPMENT
• FUTURE STUDIES
- FOREST LANDS
- ENERGY RESOURCE LANDS
- RESOURCE CONFLICT AREAS
• STUDY AREAS – OKANAGAN, S. QUEBEC,NIAGARA,ANNAPOLIS
• METHODOLOGY APPLICATIONS
- AIR PHOTO INTERPRETATION
- CLUMP LAND COVER/LAND ACTIVITY CLASSIFICATION
- 3 MONITORING CYCLES 1961,1971,1981
• OUTPUTS
- LAND USE MAPS AND CODES FOR COMPUTER INPUT
- REGIONAL AND NATIONAL LAND USE CHANGE - FRUITLANDS REPORTS
- FACT MAPS
• PROJECT DEVELOPMENT AND PLANNING
• PRELIMINARY OVERVIEW REPORT
• FOCUSSED STUDIES
- FRASER DELTA
- WESTERN PRAIRIES
- SOUTHERN ONTARIO
- ST. LAWRENCE VALLEY
- MONTREAL REGION
- TANTRAMAR MARSHES
• UCR WETLAND DATA ANALYSIS AND FACT SHEETS
• LANDSAT THEMATIC MAPPER REMOTE SENSING RESEARCH
• NATIONAL STATUS REPORT

results in the Okanagan, for example, show that while the fruit growing area declined 23% between 1961 and 1981, urban uses and recreation increased by 242%.[1] The majority of the land urbanized (69%), is class 1-3 for agricultural capability. The reporting of the fruitland results is presently well underway. A major report is in final production for the Okanagan study area, and fact maps are being produced for the remaining three fruitland areas. In addition, the initial chapters of a national fruitlands land use change report are currently being drafted.

THE PRIME WETLANDS PROJECT

The above provides a synoptic overview of CLUMP activities, especially the operational projects. The remainder of this paper focusses on the Prime Wetlands project. This is the second prime resource lands project of CLUMP and was initiated in 1982. It should be pointed out that land use monitoring of wetlands change is not the only research activity of Lands Directorate devoted to wetlands. Other activities include those of wetlands classification and evaluation, the evaluation of government programs on wetlands, a review of mechanisms to preserve wetlands, and an examination of ways to increase public awareness of the wetlands problem.

The approach to the prime wetlands project under CLUMP is different from prime fruitlands. Not all prime wetlands are being monitored. A total inventory approach was not feasible recognizing the resource constraints under which CLUMP operates. Rather, selective study areas are being examined to provide representative regional examples of land use change affecting wetlands. In addition, the wetlands project relies far more on existing data sets. Some prime wetlands studies build upon available data bases while others clarify or evaluate existing information to provide quantifiable land use change data. As indicated earlier, the wetlands project under CLUMP is confined to the southern portions of Canada where significant land use change pressures exist affecting wetlands of national significance.

The goals of the Prime Wetlands Project are:

1) to develop national and regional overviews indicating the rate, nature and extent of land use changes on and adjacent to wetlands in southern Canada;

2) to illustrate wetland conversion issues in selected representative wetland regions across Canada; and

3) to develop improved research methods for monitoring land use and wetland conversions in Canada.

Rump (1983)

The major Prime Wetlands studies now complete, underway, or initiated are summarized below.

Synoptic National Report: A compilation and analysis of reports providing quantitative information on wetland conversions due to land use pressures was initiated in 1982 and published the following year. It is entitled "Land Use Change on Wetlands in Southern Canada: Review and Bibliography" by Lynch-Stewart (1983).

The report consists of four major sections. A literature review summarizes the nature and scope of existing information sources and identifies major data gaps. A national overview examines the conversion of wetlands to agricultural use, urban and industrial development, energy-related development and recreational use. A geographical breakdown of nationally and regionally-significant issues is provided for each land use type. The final section presents a summary and general recommendations related to wetlands conversion across southern Canada. Detailed descriptions of the quantitative data bases identified, and brief annotations of the qualitative sources, are appended to the report.

In this overview, eighteen studies across Canada were identified that provide facts and figures on wetland conversion. Eight of these studies, and three additional ones recently completed are listed in Table 1, all having been undertaken in Alberta, Saskatchewan, Manitoba and British Columbia. The remainder of the studies covered in the Lynch-Stewart (1983) report are concentrated in Ontario and Quebec.

TABLE 1: QUANTITATIVE WETLAND LAND USE CONVERSION STUDIES IN WESTERN CANADA

	Region and Authors	Study Area Size	Era	Net Wetland Change Results
1	Aspen Parkland, (Alta.) (Schick, 1972)	699 km^2	1900-1970	61% loss (area)
2	Battle River Basin (Alta.) (Ritter, 1979, 1980)	301 km^2	1800-1978	9% loss (area)
3	South Saskatchewan River Basin (Alta.) Schmitt (1980)	45 km^2	1800-1979	21% loss (area)
4	Southern Saskatchewan (Sask.) (Millar, 1981)	82 km^2	1950-1980	27% permanent impact (no. of sites)
5	Black Soil Zone (Alta., Sask., Man.) (Goodman and Pryor, 1972)	21 km^2	1940-1970	13% loss (area)
6	Newdale Plain (Man.) (Adams and Gentle, 1978)	248 km^2	1964-1974	17% affected 7% eradicated
*7	Valley River Watershed (Man.) (Pokrant and Gaboury, 1983)	1 786 km^2	1948-1981	37% loss
8	Minnedosa Pothole Region (Kiel et al, 1972)	131 km^2	1928-1964	27% loss (area)
9	Minnedosa Pothole Region (Rakowski et al, 1974)	131 km^2	1964-1974	40% loss (area)
*10	Minnedosa Pothole Region (Rakowski and Chabot, 1983)	131 km^2	1974-1982	41% loss (area)
*11	Southwestern Fraser Delta (Pilon and Kerr, 1984)	524 km^2	1967-1982	27% converted 11% loss (area)

*Studies not outlined in Lynch-Stewart (1983)

While many wetland evaluation and research studies have been undertaken to create a vast wealth of ecological and policy oriented literature, only these few studies exist to indicate the rate and extent of wetland conversions in Canada. They cover less than 5% of southern Canada's land area and provide only a small window on the status of southern wetlands. Unfortunately, all of these studies are virtually uncomparable having been undertaken for varying time periods, with different methodologies and inconsistent data sources, by different agencies, and for a wide range of reasons and objectives.

The intense conflict over prairie wetlands for wildlife and waterfowl habitat versus agricultural use is the most extensively documented wetland issue in Canada. Eleven studies in the four western provinces provide some data on past and current general trends. Losses have been progressive and severe and continue today.

Several studies have focussed on the Minnedosa pothole region of southwestern Manitoba. Kiel et al (1972) for the 1928-64 period have shown a conversion of wetlands for the Minnedosa region due to: (a) clearing and cultivation of surrounding basins; (b) infilling and road construction; and (c) complete or partial drainage. Over 50% of the available potholes were noted to have been adversely affected by these practices but only 27% were deemed to be permanently "lost". Rakowski et al (1974) reported a further 40% decline in the Minnedosa wetland area from 1964-74. Subsequently, Rakowski and Chabot (1983) report a continuing loss of a further 41% of the wetlands during the period from 1974 to 1982. In 1928 wetlands covered 13.2% of the Minnedosa region but by 1982 they only covered 3.8%. A separate study by Adams and Gentle (1978) indicated that 17% of the Minnedosa wetlands from 1964-74 were altered by clearing of wooded perimeters or by partial drainage and 7% of the available ponds were eradicated permanently in that period. The startling fact here is that the rate of loss in wetlands in the Minnedosa region appears to be progressively increasing with time.

Several broader regional studies have focussed on western Canada wetlands. Goodman and Pryor (1972) examined wetlands on 600 randomly selected quarter sections across the Black soil zone of Alberta, Saskatchewan and Manitoba for the 1940-1970 period and reported a total 13% loss of wetland area (with an additional 6% adversely affected). Millar (1981) reported detailed surveys of selected transects in southern Saskatchewan from 1950-1980. Over 27% of selected quarter sections show permanent wetland change impacts while 73% have had short-term transitory impacts.

Selected watershed basins have been studied in western Canada as well. Ritter (1979, 1980) examined the Battle River Basin in Alberta showing a severe loss of waterfowl habitat due to ditching and drainage (9% of water bodies and 18% of available river shorelines) from initial settlement to 1978. Studies by Schmitt (1980) on the South Saskatchewan River revealed similar wetland conversion results (21% of water bodies and 15% of shoreline wetlands being lost) from settlement to 1979.

Other key studies include Schick (1972) who studied a small area of the Alberta Parkland Region documenting a loss of 61% of the wetlands from 1900-1970. A study of the Valley River Watershed in Manitoba by Pokrant and Gaboury (1983) from 1948-1981 indicates a loss of 37% of wetlands in this basin.

The overview of existing information by Lynch-Stewart (1983) was used to plan the location of a series of focussed studies under the Prime Wetlands project. These were designed to infill gaps in regional data to develop a more complete national overview of wetlands conversions. Attempts were made to use a standard approach for these studies. For example, the research focusses on contemporary changes over the last 20 years using either the CLI or CLUMP land use classifications and data sets. A description of these studies giving brief summaries of results wherever possible is provided below.

Southwestern Fraser Lowland (B.C.) - This project examined land use change on wetlands within a portion of British Columbia's Southwestern

Fraser Lowland. Wetlands are identified on the basis of soil and habitat characteristics. A map of these wetland areas was superimposed on land use maps for 1967 and 1982 to obtain change data. The analysis focussed on the dynamics of land use change on wetlands for built-up, agricultural, recreational and extractive land uses, as well as 'natural' wetlands. Natural wetlands were defined as wet soil areas with unaltered natural vegetation cover and no known land use. It reveals that 27% of natural wetlands in the study area were converted between 1967 and 1982 but only 11% were permanently "lost". Much of the remainder was actually a change to recreational and conservation uses which would preserve the natural wetlands. Built-up uses on wetlands almost doubled during this same period, resulting in a permanent wetlands loss. The final report for this study has been published (Pilon and Kerr, 1984).

British Columbia Wetlands - A study is in progress by B.C. Research of Vancouver to interpret and evaluate land use and vegetation changes for a series of wetland test areas in British Columbia using LANDSAT Thematic Mapper digital data. Results are anticipated in mid-1985. The project is jointly funded by the Canadian Wildlife Service and Lands Directorate of Environment Canada and the Unsolicited Proposals Fund of Supply and Services Canada. It is focussing on development of a precise wetland land use/cover and ecological monitoring system for coastal, riverine and interior wetland situations.

Southern Ontario - This project has produced maps of the wetlands of southern Ontario on 125 1:50 000 scale maps. The study uses overlays of topographic maps with CLI land use and soil capability maps. All soil capability classes with a wetness limitation (subclass "W") and organic soils (class "O") are overlain with land use maps. Wherever natural vegetation classes for marsh (class "M") and forest (classes "T" and "U") coincide with wet soils, it has been assumed that a wetland existed in 1966. If a wet soil does not overlay with the above land use classes, it is assumed that the wetland has been converted to other uses. These studies indicate that 70% of the original, pre-settlement wetlands in southern Ontario had been converted by 1966 to other uses. About 54 100 km^2 of wetlands existed in 1966 in Southern Ontario (Snell, 1981). Currently, these maps are being updated to 1982 to produce a final "Wetland Map Series for Ontario" by early 1985 in cooperation with the Canadian Wildlife Service and Ontario Ministry of Agriculture and Food. Preliminary results indicate that wetland losses over southern Ontario from 1966-82 have been major only in certain counties. For example, wetland losses in the counties of southwestern Ontario are severe, ranging from 11-24% in the area from Windsor to London.

An evaluation of this methodology for potential application in other areas of Canada has also been completed (Kessel-Taylor, 1984a). Test areas in Manitoba and Nova Scotia were evaluated. In addition, the suitability of this approach for use with CLUMP Urban Centered Region (UCR) data sets was evaluated. Subsequently, application of the approach to all major UCR's in Canada was undertaken (Kessel-Taylor 1984b), and is outlined in this paper in a section that follows.

Montreal Region - An evaluation of wetland conversion on 11 1:50 000 map sheets surrounding Montreal has been completed for the 1966-1981 period. This study covers an area of 4 020 km^2. A final report and map at 1:100 000 is in preparation. Comparison of land use maps, and new aerial photograph interpretation were applied using manual overlay techniques. Results indicate only 1.4% of the study area was wetland in 1981 with a loss of 406 ha from 1966-81. Major causes of this 7% loss of area were agriculture (25%), urban growth (14%), landfill (11%), industry (10%), and road construction (21%).

St. Lawrence Valley - In cooperation with the Canadian Wildlife Service, a report summarizing and highlighting several previous studies of wetland conversions for the 1950-1978 period along the shores of the St. Lawrence River in Ontario and Quebec and adjacent Quebec rivers is now completed in draft form, with a final report expected by December 1984.

The original reports undertaken by Le Groupe Dryade Ltée for the Canadian Wildlife Service are not widely distributed but contain data on what is considered the most definitive study of wetland and land use interactions yet undertaken in Canada. They compare the land use causal factors for wetland losses on a series of shoreline segments for the entire St. Lawrence River and Estuary from Cornwall to Matane. Overall these areas have lost over 42% of the wetlands during the post-war period, mainly from 1950-65. The major causes of decline are shoreline fill (27%), drainage for cropland and grazing land (33%) and residential expansion (12%).

Tantramar Marshes - A study to evaluate the extent, rate, and nature of changes to salt marsh wetlands in the Tantramar region of New Brunswick and Nova Scotia was initiated in September 1984. It will produce land use change data for the period 1961 to 1981 using the CLUMP classification (Gierman, 1981). The Tantramar marshlands have had agricultural development since the early 18th century. The area is currently experiencing agricultural decline resulting in destruction of dyke systems and increases in salt marsh vegetated area.

Urban Centred Regions - As indicated previously in this paper, a project has been completed to apply a slightly modified version of the wetland conversion technique developed for the Ontario Wetland Map Series (Snell, 1981) to urban centred regions. This has permitted production of statistics and colour maps of 23 major Urban Centred Regions including Vancouver, Victoria, Edmonton, Calgary, Regina, Saskatoon and Winnipeg showing the extent and location of wetlands. Major UCR's are defined as having a population in excess of 100 000 in 1981. Three time periods are identified: pre-settlement, 1965, and the most recent land coverage available, usually 1981 (Kessel-Taylor, 1984b).

The methodology for these UCR wetland studies has involved interactive evaluation of computerized geographic data bases for each UCR. Through computerized map overlay, retrieval, and analysis with the Canada Land Data System, colour graphics, maps, and data tables for all western cities have been developed. A final report on these studies and fact sheets on wetland conversions for each UCR are currently in preparation (Kessel- Taylor, 1984b).

An example of the UCR Wetland dynamics analysis is presented here for Vancouver. The data table developed for Vancouver is shown in Table 2. Maps generated by computerized data base analysis and terminal display were also produced for each of the 23 UCRs to depict the location of presettlement and currently existing wetlands. Figures 3 and 4 depict examples of these maps for Vancouver. Table 3 summarizes the conversion statistics for wetlands within the seven major UCR study areas in Western Canada. Preliminary summaries of the nature of these conversions for Vancouver, Victoria, Edmonton, Calgary, Saskatoon, Regina and Winnipeg are outlined below. Estimates of total wetlands for each of these UCR are limited by CLI complexed data, a 1:50 000 minimum map unit limitation of 2.5 ha and the variable and seasonal nature of many prairie wetlands.

Vancouver: The growth of Vancouver has been concentrated on the Fraser River Delta. Residential growth onto the flat delta land resulted in an 82% expansion of the built-up area of Vancouver from 1966-81, largely into agricultural land. From settlement to 1966, about 78% of the wetlands originally in the Vancouver UCR area were converted to other uses, mainly to agricultural land. However, from 1966-81 only a minor amount of the wetlands in the Vancouver area was further lost. In the same period 1966-81, recreational land tripled in total area indicating some of the wetlands converted in fact are now protected. In 1981, remaining wetlands comprised at least 9,842 ha, or about 5%, of the Vancouver UCR total area of 180,067 ha.

Wetlands in the southwestern Fraser Delta area, a subset of the total Vancouver UCR, have been studied separately indicating that from 1967-82, 28% of the wetlands underwent land use conversion but at least half of this was into recreational or non-destructive uses (Pilon and Kerr, 1984). The results of this additional study contrast with those for the total UCR indicating the Fraser Lowland is a particularly dynamic area.

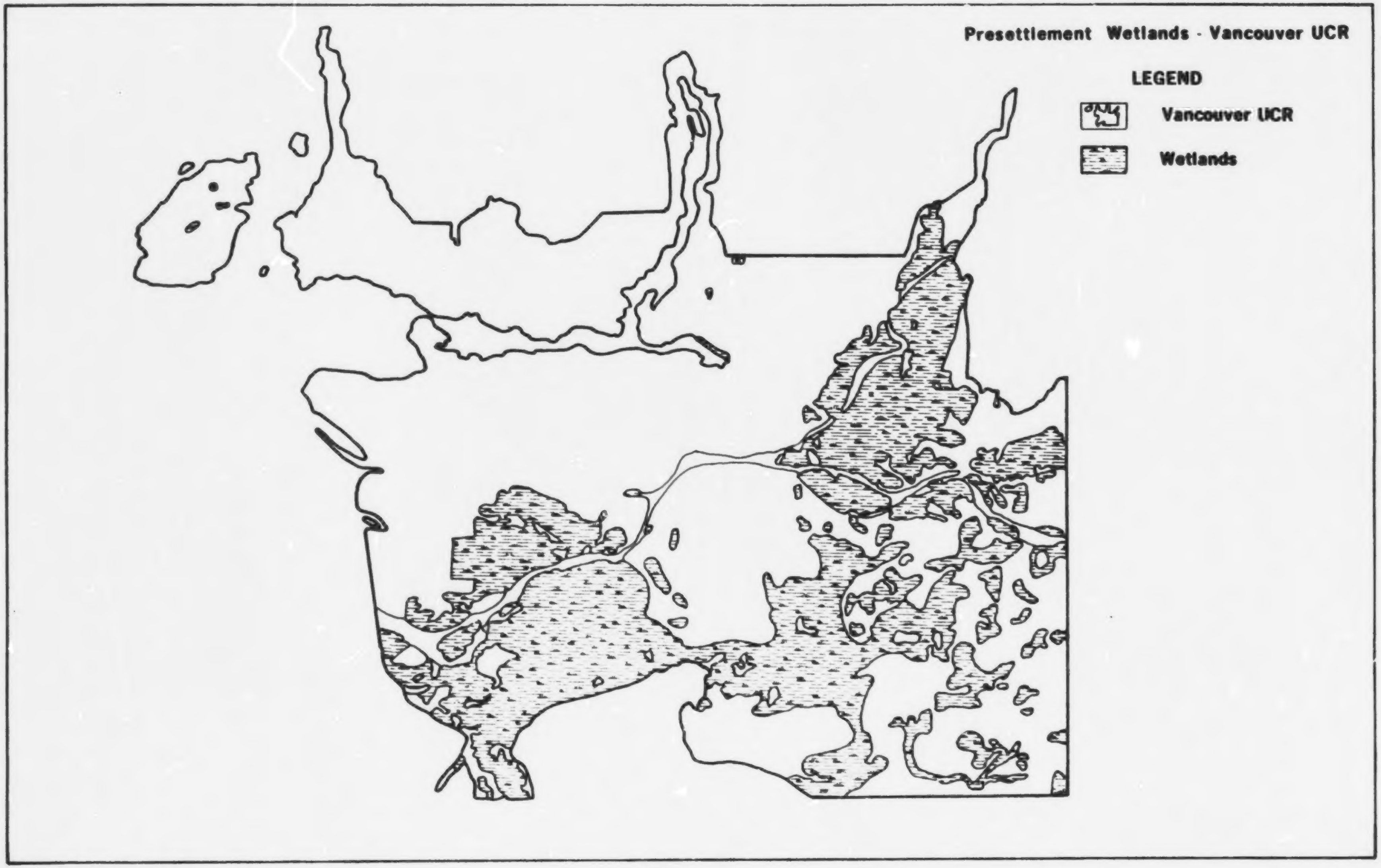
TABLE 2

LAND USE DYNAMICS ON WET SOILS FOR THE VANCOUVER UCR

LAND USES[1] ON WET SOILS IN VANCOUVER UCR	1800[2] AREA (HA)	1966 AREA (HA)	1971 AREA (HA)	1976 AREA (HA)	1981 AREA (HA)	1966-1981 CHANGE (HA)
NATURAL COVER	46,200	10,209	9,842	10,039	9,842	- 367
IMPROVED AGRICULTURE	--	24,207	24,845	23,340	22,822	- 1,358
UNIMPROVED AGRICULTURE	--	7,789	6,647	5,970	1,734	- 6,055
RECREATION	--	390	437	1,215	3,583	+ 3,193
URBAN USES	--	3,605	4,429	5,616	8,219	+ 4,614
TOTAL	46,200	46,200	46,200	46,200	46,200	

[1] For a description of land use classes see Gierman (1981).

[2] For this study, the total wet soil area identified by CLI is considered to approximate the presettlement wetland situation. The year 1800 was arbitrarily selected to identify presettlement wetland.



Presettlement Wetlands - Vancouver UCR
LEGEND
Vancouver UCR
Wetlands

Figure 3 - LOCATION OF WETLANDS IN VANCOUVER UCR AREA AT SETTLEMENT (1800)

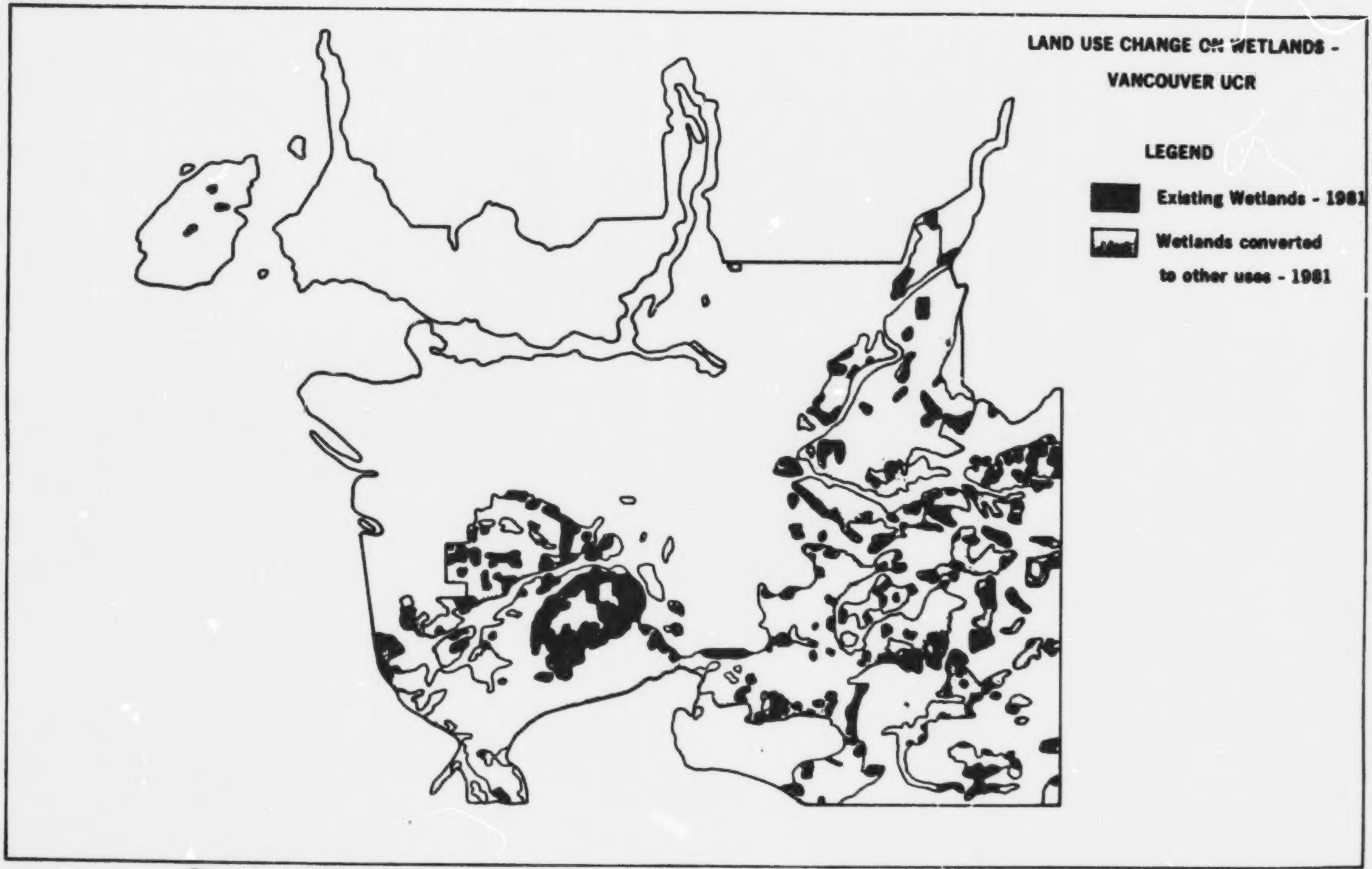

LAND USE CHANGE ON WETLANDS -
VANCOUVER UCR
LEGEND
■ Existing Wetlands - 1981
▨ Wetlands converted to other uses - 1981

Figure 4· LOCATION OF 1981 REMAINING WETLANDS AND WETLANDS CONVERTED TO OTHER USES

TABLE 3: WESTERN CANADA MAJOR URBAN CENTRED REGIONS WETLAND CONVERSION SUMMARY

Urban Centred Region	Area of UCR (km^2)	Area of Wetlands Circa 1800 (Settlement)* (km^2)	Current Area of Wetlands (1976 or 1981) (km^2)	% Loss to Present (1976 or 1981)
Vancouver	180.07	46.20	9.84	79
Victoria	86.08	4.80	1.17	75
Edmonton	625.01	32.52	7.80**	76**
Calgary	281.88	4.14	0.92**	78**
Saskatoon	70.82	0.99	0.06	94
Regina	100.90	1.55	0.03	98
Winnipeg	181.99	134.01	3.96	97

*1800 is arbitrarily chosen as the settement date.

**Data for 1976.

Victoria: The built-up urban area of Victoria almost doubled from 1966-81. The rugged coastline and interior of Vancouver Island has confined urban expansion into discontinuous lowland agricultural land and scattered wetlands. Up to 1966, it is estimated that 70% of the original wetlands present had been converted. From 1966-71, no major decline in total wetland area is evident from the data analysis but from 1971-81 a further 250 ha or 5% of the original wetland area was converted to other uses. However, some of this amount was into recreational uses. In 1981, at least 1,169 ha of natural wetlands remained, covering about 1% of the Victoria UCR total area of 86,076 ha. Several unique areas of remaining wetlands have been identified by conservation agencies including Witty's Lagoon, Alberthead Lagoon, and the marshes in Tsehun Harbour.

Edmonton: This UCR is one of the most rapidly growing urban areas in Canada. The built-up urban area of the city almost tripled from 1966-76. There is a high density of small, semi-permanent sloughs and potholes within the UCR making the estimate of total potential wetlands somewhat low since it excludes all areas less than 2.5 ha. Analysis of CLI data indicate that for the wetlands captured in this study, over 79% of those wetlands which existed at the time of settlement had been converted to other uses by 1966, largely due to agricultural drainage. The analysis suggests that the area of wetlands in the UCR increased between 1966 and 1971 and then declined between 1971 and 1976. In 1976, it is estimated that wetlands covered at least 7,799 ha or about 1% of the Edmonton UCR area of 625,012 ha.

Calgary: This is another rapidly growing urban centred region. Analysis of CLI agriculture capability data for wet soils and organic soils indicated that less than 4,200 ha of presettlement wetlands ever existed in this UCR. The location of these wetlands was concentrated on the east and west of the urban core. The trend in wetland conversion in this analysis for Calgary is based only on a subset of all the possible wetlands likely present. From settlement to 1966, 76% of the identified wetlands in the Calgary area were converted to other uses, mainly to agriculture. From 1966 to 1981, the remaining wetland area remained basically stable. The Priddis Slough and Radio Tower Slough have recently been recommended for conservation protection. It is estimated that in 1981 wetlands covered 919 ha or only 0.3% of the total Calgary UCR area of 281,883 ha.

Saskatoon: From 1966 to 1981, this UCR increased in built-up area by 28%. Presettlement wetlands, based on analysis of CLI data, were concentrated to the northeast of the present airport and to the west of the urban core. The Canadian Wildlife Service has estimated that in the vicinity of Saskatoon at least 210 small wetlands per km^2 can be expected (Millar, 1981). Hence, the estimate here of total wetlands is likely to be low. However, for those wetlands captured in this analysis, at least 98% were converted to other uses by 1981. For 1981, only 0.1% of the Saskatoon UCR area of 70,823 ha is recorded in this study as having wetlands.

Regina: From 1966 to 1981, the built-up area of Regina increased by 70%. Wetlands in this area are generally scattered wet meadows and fresh to saline small marshes, potholes and sloughs. Of the wetlands captured by this analysis, 58% of those existing at the time of settlement had been converted to other uses by 1966, mainly to agriculture. From 1966 to 1976, the wetland area remained almost stable but from 1976 to 1981 there was a significant decline in the total remaining, largely due to land drainage for agriculture. In 1981, only 2% of the original wetlands in the Regina UCR remained.

Winnipeg: This UCR is located on an extensive plain, which before settlement was almost all poorly drained wetlands. The Winnipeg UCR increased in built-up area from 1966 to 1981 by 15%. Analysis of CLI agricultural data indicates that at least 74% of the Winnipeg UCR was once wet or organic lands. It is estimated that 96% of the wetlands present at settlement in the UCR were converted to other uses by 1966, mainly through agricultural drainage. From 1966-81, a further 700 ha of wetlands were converted. In 1981, it is estimated that 3,962 ha of wetlands remained or 2% of the total UCR area of 181,987 ha. While conversion pressures are continuing in Winnipeg, the total area of recreational land increased from 1,500 to 5,400 ha between 1966 and 1981, probably leading to some wetland preservation.

Western Prairies Study: The Lands Directorate is planning a specific study on wetland conversions in the rural areas of Western Canada. Such a study is greatly needed to provide comparability and compatibility with our focussed studies in other regions of Canada. Planning for this study has recently been enhanced by the Directorate's location of a new regional office at Regina in August 1984. The Directorate would welcome suggestions for priority areas of study and proposals for cooperative ventures that would contribute to our national perspective on the status of wetlands in Canada.

Initial efforts to develop appropriate study transects or sites in Manitoba and Saskatchewan have been explored with the Canadian Wildlife Service building upon the numerous studies outlined in Table 1. The study we propose would commence in early 1985 with a one year maximum time frame for completion. It would likely focus on conversions since 1974 in areas where earlier data is available.

ROLE OF LAND USE CHANGE RESEARCH

Land use change research provides a better understanding of the uses and management of the land resource base and the implications for long-term sustainable renewable resource use. This is particularly significant in the case of prime resource lands such as wetlands, which are highly productive and form the fundamental base for renewable resource products. From the data available, it is evident that the vast majority of wetlands were converted to other uses, primarily agriculture, prior to 1960 in southern Canada. Wetlands were once abundant, but are now a scarce prime resource land and warrant special attention in terms of measures to protect their inherent attributes. In many areas the amount of remaining wetlands is severely limited (e.g. less than 1% in many urban centred regions; 3.8% in the Minnedosa area). Yet significant increases in the production of land-based commodities, such as those forecast by the year 2000 for agriculture (65% increase in production), could result in further wetlands loss unless an effective multi-sector planning and management perspective for prime resource lands can be attained at all levels of government.

A land use monitoring program should provide a comprehensive and systematic information base on land use changes taking place. It must provide a quantitative assessment of the changes including their location, magnitude, and implications. The outputs of such a program give profile and help promote the retention of the high quality productive lands so important to the national well-being. This information facilitates the analysis of land use change in terms of causes and consequences, including the evaluation of the impact of government programs and policies.

This presentation on the Canada Land Use Monitoring Program has demonstrated this role in the context of the Prime Wetlands project. Our first objective is to provide a national perspective on wetlands loss for federal information requirements. This is to provide a sufficient data base to improve federal policies and programs from an environmental and sustainable resource viewpoint. It is not specifically intended to provide encompassing data for all the wetland areas in Canada. In the north, for example, the need exists for wetland baseline information rather than land use change. This need is being addressed by other Lands Directorate activities such as the Northern Wetlands Research Project (Lynch-Stewart, Helie, and Ouimet, 1984) covering the Beaufort Sea and Northwest Passage Regions. Under the Canada Land Use Monitoring Program, the ultimate objective is to prepare a national status report on the rate, extent, and implications of wetland land use conversions across Canada using both our own studies and existing data from other sources. This report, sections of which are already in preparation, is expected to be published in 1986.

REFERENCES

ADAMS, G.D. and G.C. GENTLE. (1978). Spatial Changes in Waterfowl Habitat, 1964-1974, on Two Land Types in the Manitoba Newdale Plain. Canadian Wildlife Service, Environment Canada, Saskatoon. Occasional Paper No. 38. 29 p.

GIERMAN, D.M. (1981). Land Use Classification for Land Use Monitoring. Lands Directorate, Environment Canada. Working Paper No. 17. 40 p.

GOODMAN, A.S. and S.P. PRYOR. (1972). A Preliminary Study of the Methods and Rates of Alteration of Waterfowl Habitat in the Black Soil Zone of Western Canada. Canadian Wildlife Service, Environment Canada, Edmonton. Unpublished. 77 p.

KESSEL-TAYLOR, I. (1984a). An Evaluation of A Methodology (Snell, 1981) For Determining Presettlement and Existing Wetlands in Canada. Lands Directorate. Environment Canada. Misc. Contract Report. 50 p.

KESSEL-TAYLOR, I. (1984b). A Quantitative Analysis of Wetland Land Use Dynamics on Wetlands for Urban Centred Regions in Canada. Contract Report, Lands Directorate, Environment Canada. 71 p. and graphics.

KIEL, W.H. Jr., A.S. HAWKINS, and N.G. DERRET. (1972). Waterfowl Habitat Trends in the Aspen Parkland of Manitoba. Canadian Wildlife Service. Report Series No. 18. 61 p.

LYNCH-STEWART, P. (1984). Land Use Change on Wetlands in Southern Canada: Review and Bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. 115 p.

LYNCH-STEWART, P., R. HELIE, and D. OUIMET. (1984). Northern Wetlands Research Project: Procedures, Results and Guidelines. Part I: Final Project Report (Draft). Lands Directorate, Environment Canada. 53 p.

MILLAR, J.B. (1981). Habitat Changes in Saskatchewan, Waterfowl Evaluation Program. Project Report. Canadian Wildlife Service, Environment Canada, Saskatoon. 60 p.

NATIONAL WETLAND WORKING GROUP. (1984). Wetland Distribution in Canada. Map with Text. In Press. National Atlas of Canada. Energy, Mines and Resources Canada.

PILON, P. and M.A KERR. (1984). Land Use Change on Wetlands in the Southwestern Fraser Lowland, British Columbia. Lands Directorate Environment Canada. Working Paper No. 34. 31 p. and map.

POKRANT, H. and M. GABOURY. (1983). Remote Sensing to Assess Land Use/Land Cover Changes Affecting the Dauphin Lake Fishery. Remote Sensing Centre, Manitoba Surveys and Mapping Branch. Winnipeg. 35 p.

RAKOWSKI, P.W., R.W. NERO and R.C. HUTCHINSON. (1974). Present Status of Waterfowl Habitat in the Prime Duck Production Area of Manitoba. Unpublished Report. Canadian Wildlife Service, Environment Canada. Winnipeg. 12 p.

RAKOWSKI, P.W. and B.P. CHABOT. (1983). Changes in Land Use in the Minnedosa District of Southwestern Manitoba: An Update on the Kiel-Hawkins Transect. Canadian Wildlife Service, Environment Canada. Winnipeg. Unpublished Report. 15 p.

RITTER, A. (1979). Wetland Reconnaissance Within the Battle River Basin: 1978 Summary. Ducks Unlimited (Canada). Unpublished. 36 p.

RITTER, A. (1980). Wetland Reconnaissance Within the Battle River Basin: 1979 Summary. Unpublished Report. Ducks Unlimited Canada. 25 p.

RUMP, P.C. (1983). Land Use Monitoring in Canada. Proc. Int. Conf. Renewable Resources Inventories fr Monitoring Changes and Trends. Corvallis, Oregon. 4 p.

SCHICK, C.D. (1972). A Documentation and Analysis of Wetland Drainage in the Alberta Parkland. Canadian Wildlife Service, Environment Canada. Edmonton. Unpublished. 15 p.

SCHMITT, K. (1980). Wetland Reconnaissance Within the South Saskatchewan River Basin. Ducks Unlimited (Canada). Unpublished. 29 p.

SEGUIN, J. and P.C. RUMP. (1984). Land Use Change Research: Canada's Fruitlands. Proc. Annual Conf. of Canadian Society Soil Science. Banff. 16 p.

SNELL, E.A. (1981). An approach to mapping the wetlands of Southern Ontario. Proc. Ontario Wetlands Conference, Research Session. Federation of Ontario Naturalists. Toronto.

WETLANDS: THEIR ROLE IN PRAIRIE WATER FLOW SYSTEMS AND SOIL DEVELOPMENT

Presented at the

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Water and Soil Research and
Management

"AGRICULTURAL LAND DRAINAGE"

Winnipeg, Manitoba
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presented by

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ASTRACT

This paper examines the role of wetlands in the prairie water flow system. Prairie marshes or sloughs are exemplified. Hydrology and hydrogeology are discussed in terms of their effect on wetland permanence and water quality. The influence that these factors have on prairie wetland soil development is reviewed with implications as to how some wetland soils might perform if drained for agricultural production.

TABLE OF CONTENTS

Title Page

Abstract

Table of Contents

1.0 INTRODUCTION

1.1 What is a Wetland?
1.2 Prairie Potholes or Sloughs

2.0 HYDROLOGY OF PRAIRIE SLOUGHS

3.0 SLOUGH FOCUSED SOIL DEVELOPMENT

3.1 Soils in Recharge Areas
3.2 Soils in Transitional Areas
3.3 Soils in Discharge Areas

4.0 CONCLUSIONS

LITERATURE CITED

Figures

1 Diagram illustrating the relationship among the major attributes used in wetland definition

2 Location of prairie slough region of North America

3 An intermediate and regional groundwater flow system

4 Topographic relationships and soil profile characteristics associated with sloughs

1.0 INTRODUCTION

Conflicting interests (Bardecki 1984 and Brande 1980) in wetlands over the past few decades have sparked a need to identify and classify wetland types. This identification and classification process has led to the collection of a significant amount of data on wetland characteristics from hydrological, hydrogeological, pedological, biological and ecological points of view, to name a few.

This information gathering process is far from complete. For example, the hydrological variation between wetlands is not yet fully understood and is still under investigation. In many cases, the variation that has been found to exist between wetlands within the same local area is so complex as to defy precise descriptions.

However, recent studies have explored both the hydrological and pedological processes associated with wetlands. The research has been comprehensive enough to allow reasoned and substantiated speculation on how wetlands function in the prairie environment and what potential these wetlands might have for agricultural development after drainage.

1.1 What is a Wetland?

The U.S. Fish and Wildlife Service (Cowarding 1982) defines a wetland as follows:

> "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" and "For the purposes of classification, wetlands must have one or more of the following attributes:

- at least periodically, the land supports predominantly hydrophytes;
- the substrate is predominantly undrained Gleysolic or Organic soils; and
- the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."

The definition requires one or more but not all of these attributes.

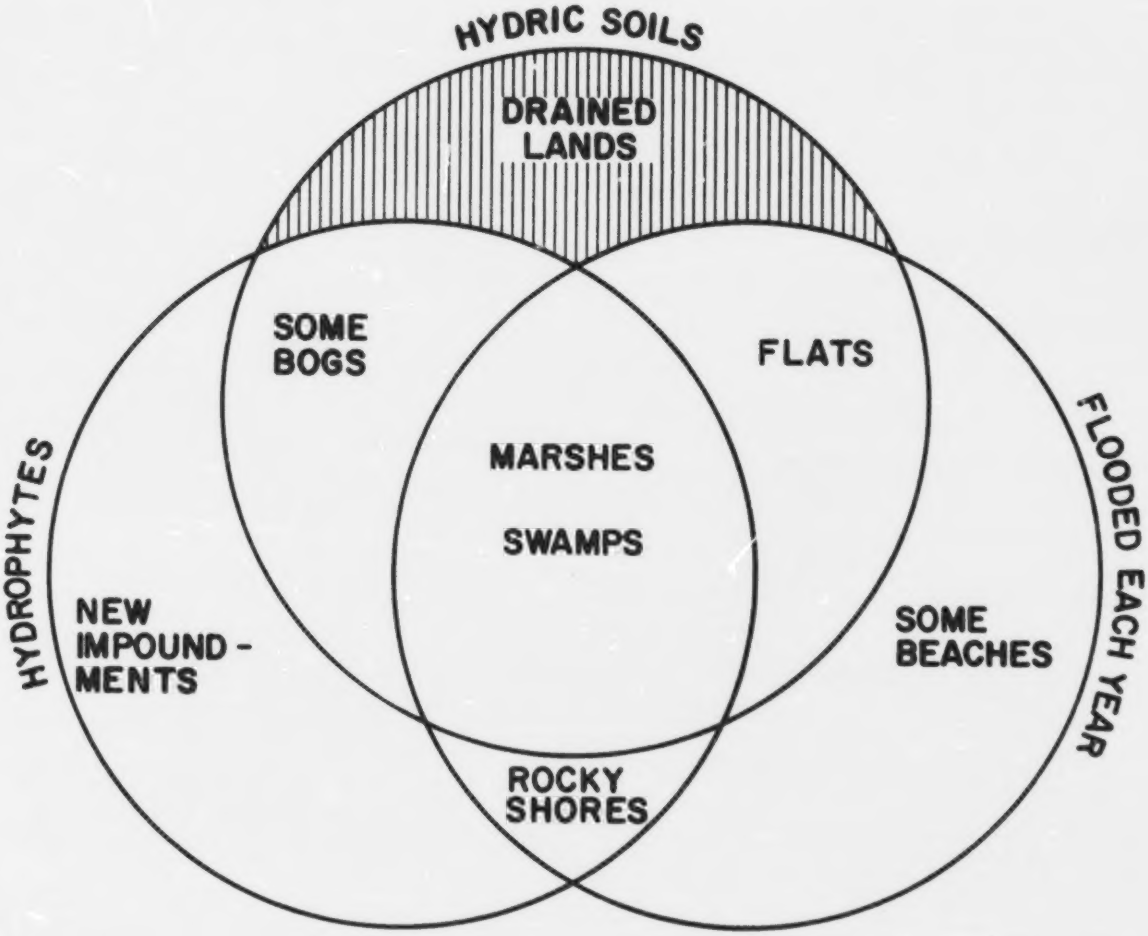
The term "wetland" can encompass numerous ecological systems. Figure 1 presents a diagram illustrating the relationship among the major attributes used in wetland definition. The wetlands identified include:

- flats;
- some beaches;
- rocky shorelines;
- new impoundments;
- some bogs; and
- marshes.

The types of wetlands discussed in this paper are classified as marshes (Millar 1976, Stewart and Kantrud 1972) and commonly referred to as prairie potholes or sloughs.

1.2 Prairie Potholes or Sloughs

Prairie potholes or sloughs are water holding depressions of glacial origin that occur in the prairies of north central United States


HYDRIC SOILS
DRAINED LANDS
SOME BOGS
FLATS
MARSHES
SWAMPS
HYDROPHYTES
NEW IMPOUND - MENTS
FLOODED EACH YEAR
SOME BEACHES
ROCKY SHORES

▥ NONWETLAND BY DEFINITION

Figure 1. Diagram illustrating the relationship among the major attributes used in wetland definition.

Source : Lewis M. Cowardin, 1982. Wetland and deepwater habitats: A new classification. Journal of Soil and Water Conservation. March-April and south central Canada (Figure 2). Prairie potholes occur in greatest number and variety in hummocky knob-and-kettle topography (stagnation moraine) created by glacial stagnation. It has been estimated that slough dotted parkland and prairie landscapes occupy more than 77 million hectares of North America (Petsnik 1975). Sloan (1970) observed that a frequency of one hundred or more sloughs per 259 hectares (one section) was not uncommon over much of this area.

Pothole size ranges from a small fraction of a hectare to several hundred hectares although potholes larger than 15 hectares are usually called lakes. Most prairie potholes are shallow and seldom exceed one metre in depth.

Salinity and depth can vary considerably on both an annual and seasonal basis. Salinity of water in potholes range from fresh to brines that can be several times more concentrated than sea water[1].

Differences in climate, geology, groundwater conditions, topography, land use, and other factors create wide differences in the hydrologic regime of potholes. Permanence of water in the potholes ranges from only a few days after spring snow melt to more or less permanent ponds.

---

[1] The predominant salt in fresh water potholes is calcium bicarbonate ($Ca\ (HCO_3)_2$). Magnesium sulphate ($MgSO_4$) predominates in brackish potholes, whereas sodium sulphate (Na_2SO_4) is the primary constituent in saline potholes (Rozkowski 1967).

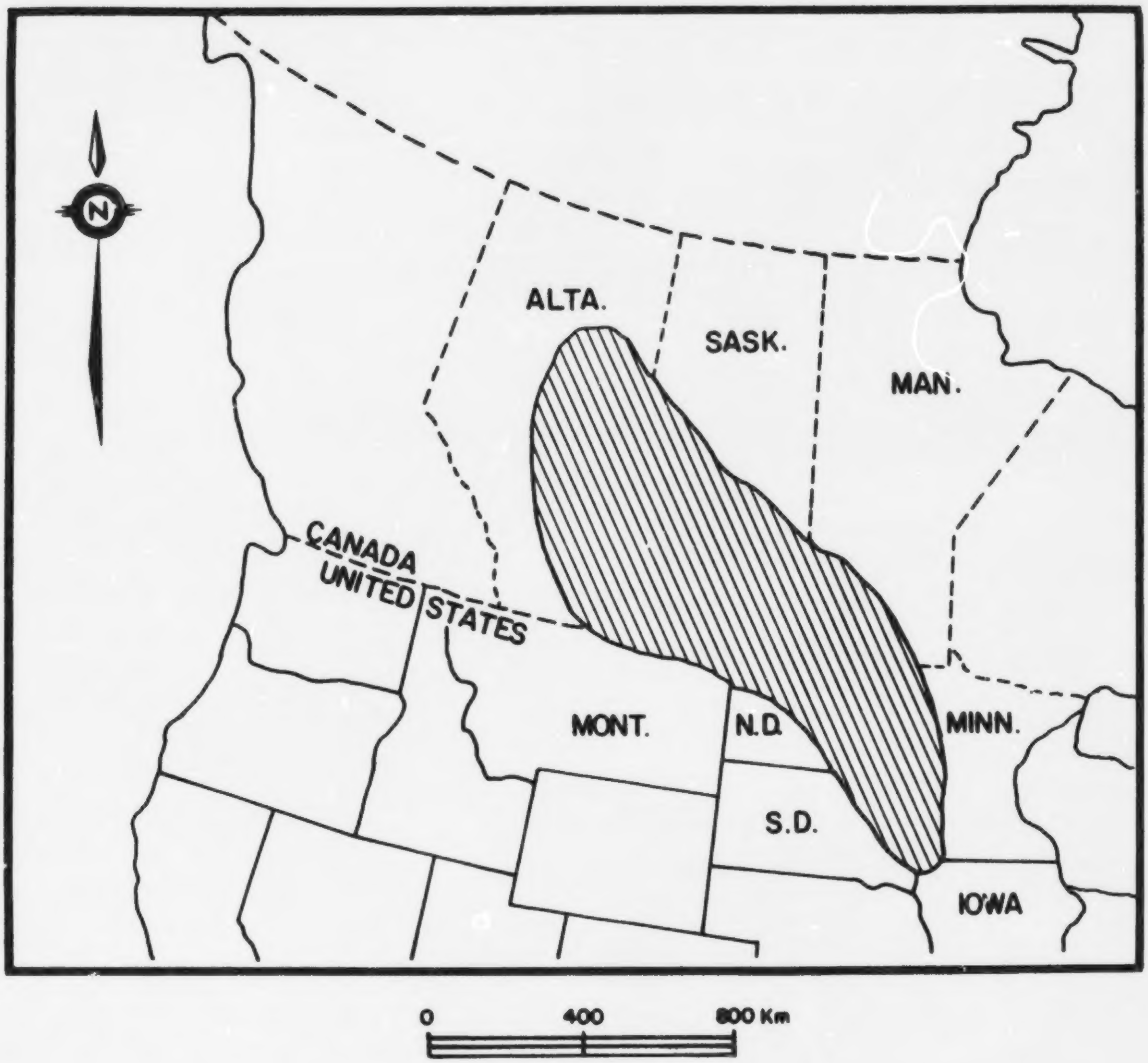

N
ALTA.
SASK.
MAN.
CANADA
UNITED STATES
MONT.
N.D.
MINN.
S.D.
IOWA
0
400
800 Km

Figure 2: Location of prairie slough region of north america

Source : J. Petsnik, 1975. Background information for the development of guidelines for prairie pothole drainage, Manitoba Department of Mines, Res. and Env. Mngt.

2.0 HYDROLOGY OF PRAIRIE SLOUGHS

Basically we know that the water supply to sloughs results from precipitation directly on the pothole, surface flow from the pothole watershed and seepage inflow from groundwater. Snowmelt, runoff in the spring and precipitation on the pothole surface are the greatest sources of water.

The mean annual levels of precipitation in the prairie pothole environment is often far less than average annual evapotranspiration. Therefore, there is a tendency for potholes to dry-up unless water loss is compensated by surface and seepage inflow.

Water losses from potholes results from evapotranspiration, overflow and seepage outflow. Dissolved solids in the pothole water can be removed by overflow or seepage outflow, but evapotranspiration removes water only as vapour and concentrates dissolved solids. In the absence of overflow, outflow seepage is the only effective mechanism for the removal of dissolved solids in the water. Thus, the relative salinity of water in potholes without overflow can be a measure of net seepage, or the inflow-outflow balance.

To a lesser extent, seepage influences permanence of water in a pothole by hastening or retarding the rate of water loss, depending upon the dominance of outflow or inflow respectively.

The seepage balance in a pothole is controlled primarily by the position of the adjacent water table rather than by the permeability of bottom sediments. Lissey (1968) explained this balance by defining an intermediate and regional groundwater flow system including recharge, discharge and transitional sloughs (Figure 3).

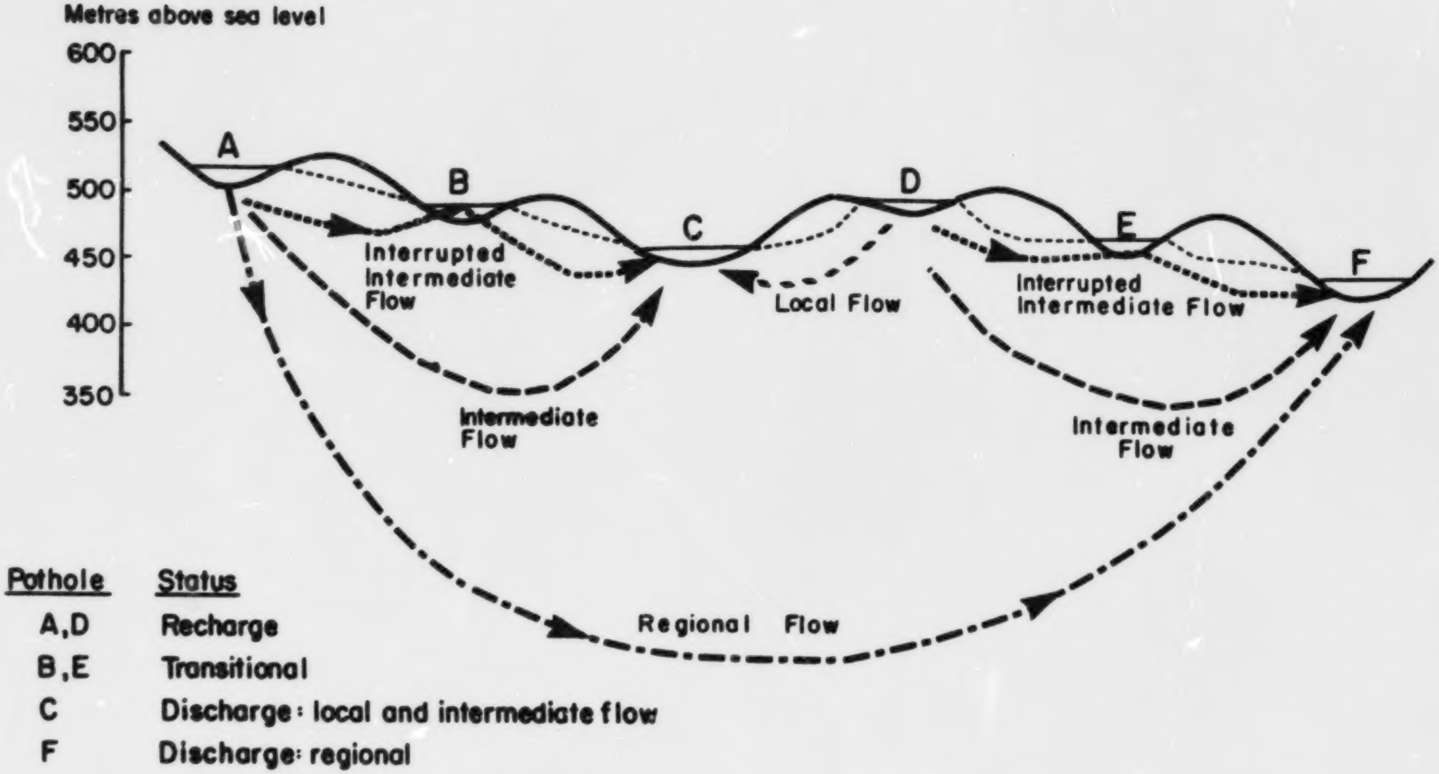

Metres above sea level
600
550
500
450
400
350
A
B
C
D
E
F
Interrupted Intermediate Flow
Local Flow
Interrupted Intermediate Flow
Intermediate Flow
Intermediate Flow
Regional Flow
Pothole
Status
A,D Recharge
B,E Transitional
C Discharge: local and intermediate flow
F Discharge: regional

Figure 3 : An intermediate and regional groundwater flow system.

Source : A. Lissey, 1968. Surficial mapping of groundwater flow systems with application to the Oak River Basin, Manitoba.

Lissey (1968), Toth (1968) and Meyboom (1962, 1966, 1967) showed (based on piezometric studies) that if the adjacent water table is lower than the pothole, seepage outflow occurs and the water is relatively temporary. Dissolved solids in the associated slough waters are usually less than 500 mg/Liter (Sloan 1970).

Recharge sloughs are characterized by fresh water hydrophytic, mesophytic and phreatophytic vegetation which is present to a greater or lesser degree dependent upon the duration of inundation after spring snow melt (Lissey 1968 and Meyboom 1996).

Lissey (1968) and Toth (1966) stated that discharge sloughs could be both saline and freshwater in nature. However, water in discharge sloughs will be relatively permanent and water levels may actually increase at some period between spring and fall. In addition, saline discharge sloughs can be quite salty with levels of dissolved solids exceeding 15,000 mg/Liter (Sloan 1970).

Discharge sloughs are conspicuous by the presence of large open water areas. Saline discharge sloughs are typified by the presence of halophytic (salt tolerant) vegetation in all periferal wetland zones.

In many potholes the adjacent water table is higher than the water surface in the pothole on one side and lower on the other which creates simultaneous seepage inflow (discharge) and seepage outflow (recharge) conditions. Lissey (1968) described these sloughs as transitional. These potholes are intermediate in permanence and salinity. Their physical features (including associated vegetation) may be similar to both recharge and discharge sloughs.

3.0 SLOUGH FOCUSED SOIL DEVELOPMENT

The influence of slough focused groundwater flow patterns on pedogenic processes is well recognized. Compared to other wetland indicators, soil attributes reflect a permanent record of the long term water regime and water chemistry. Toth (1966) stated that the appreciation of certain soil characteristics related to the prairie groundwater flow systems would help explain the development of certain wetland associated soil types and ultimately help estimate the prospects for successful slough drainage and reclamation.

Pedogenic processes that take place in a soil depend on processes such as hydration, hydrolysis, solution, oxidation, reduction, leaching, eluviation, precipitation and mixing. Water is a basic requirement in most of these processes. It follows that the direction and rate of water movement through the soil will greatly influence the type, rate and characteristics of soil development.

The sequence, type, and degree of soil profile development is an indicator of the hydrological activity of a soil. In recharge areas the net water movement is downward and soluble constituents are generally leached out of the soil. The soils of recharge areas frequently show eluviated surface horizons.

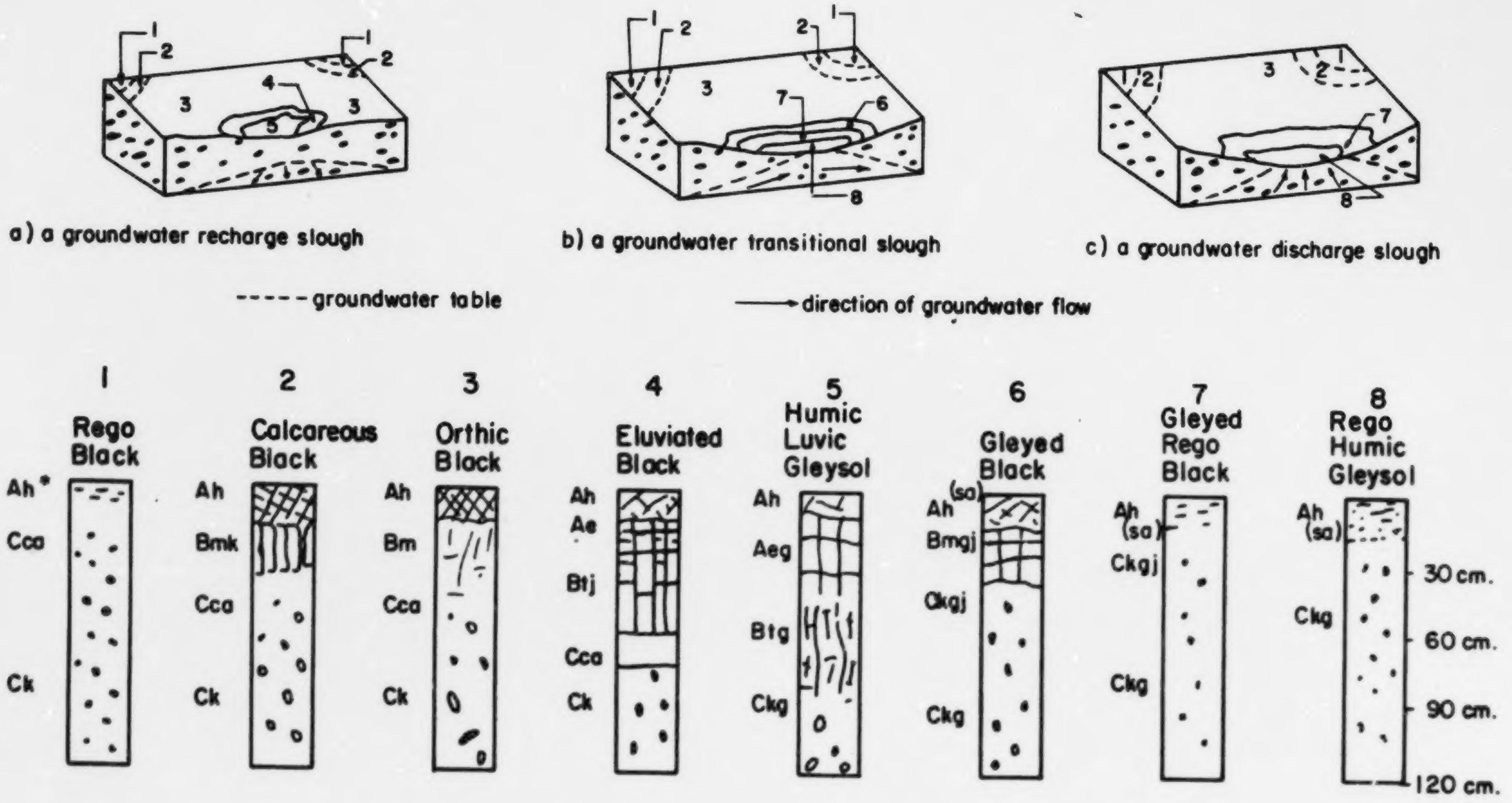
On the other hand, soil formed where the groundwater table is high and net water movement is upward, show limited soil profile development and varying degrees of salinity. Pawluk (1973) found that a groundwater table within 1 meter of the surface results in strong salinization of the upper 1 m of soil. In medium texture soils, water tables below 2 meters result in thick soil profile development. Soils containing a high concentration of soluble salts are refered to as saline soils. Saline soils are of particular importance because their presence indicates groundwater discharge conditions (Toth, 1966) and potential problems with soil drainage.

Applying the Canada Soil Classification System to the soils that exist in an around sloughs, Eilers (1973) and Rennie and Ellis (1978) indicated how soils which belong to several subclasses of two orders, namely the Chernozemic and Gleysolic would be distributed around a slough. Catena sequences commonly found in and around typical recharge, discharge, and transitional sloughs are illustrated in Figure 4 (illustrations a, b and c) with reference to their relative location and position of the groundwater table. Chernozemic and Gleysolic Orders are represented in each case to a degree indicative of the duration of surface flooding and soil saturation.

3.1 Soils in Recharge Areas

Rennie and Ellis (1978) stated that, in general, change in soil properties from the knoll to recharge depression are to a large extent related to the redistribution of precipitation. The general trends from upper to lower slope positions are illustrated in Figure 4 and can be summarized as follows:

- increased organic matter content and thickening of Ah horizon;
- loss of soluble salts from surface horizons and their movement vertically to underlying horizons;
- increased leaching and eluviation as evidenced by the development of Ahe and Ae horizons; and
- presence of marked Cca horizons in upper slope positions with more diffuse accumulations in moister lower slope profiles.


1
2
1
2
3
4
5
3
a) a groundwater recharge slough
1
2
2
1
3
7
6
8
b) a groundwater transitional slough
2
3
2
7
8
c) a groundwater discharge slough
----- groundwater table
——→ direction of groundwater flow
1
Rego Black
Ah*
Cca
Ck
2
Calcareous Black
Ah
Bmk
Cca
Ck
3
Orthic Black
Ah
Bm
Cca
Ck
4
Eluviated Black
Ah
Ae
Btj
Cca
Ck
5
Humic Luvic Gleysol
Ah
Aeg
Btg
Ckg
6
Gleyed Black
Ah(sa)
Bmgj
Ckgj
Ckg
7
Gleyed Rego Black
Ah (sa)
Ckgj
Ckg
8
Rego Humic Gleysol
Ah (sa)
Ckg
30 cm.
60 cm.
90 cm.
120 cm.

*see.... Canada Soil Survey Committee, 1978. The Canadian System of Soil Classification, published by Agriculture Canada, p.23 for explanation of suffixes.

Figure 4: Topographic relationships and soil profile chacteristics associated with sloughs.

Adapted from : D.A. Rennie and J.G. Ellis. 1978. The shape of Saskatchewan, and R.G. Eilers. 1973. Relationship between hydrologeology and soil characteristics near Deloraine, Manitoba.

3.2 Soils in Transitional Areas

The soils in transitional and discharge areas are often difficult, if not impossible, to examine. However, these soils should indicate more prolonged periods of saturation. Soil profiles presented for transitional sloughs as illustrated in Figure 4 are not as well developed as in the case of recharge sloughs and the soils may have a tendency to be calcareous and/or saline.

3.3 Soils of Discharge Areas

In the case of discharge sloughs, soil development is weak. The water table is usually near the surface and evaporation exceeds infiltration. Soils of discharge sloughs are usually wet, calcareous and saline. The location of the various soils profiles in a typical discharge area as suggested by Eilers (1973) are shown in Figure 4.

CONCLUSIONS

Prairie potholes occupy a dynamic hydrologic environment characterized by wide spatial and temporal variations. Much of the hydrologic variability is influenced by the characteristics of the groundwater flow system at the pothole. Prairie pothole soils, when accessible for inspection, are useful indicators of pothole hydrology because they represent long term average conditions, a distinct advantage for classification purposes, and a definite indicator of the role a specific wetland plays in the hydrologic cycle. Pothole soils give a historical account of each wetland and ultimately suggest the degree of success one might anticipate in wetland drainage and reclamation.

LITERATURE CITED

Bardecki, Michal J. 1984. What value wetlands? Journal of Soil and Water Conservation, May-June: pp. 166-169.

Brande, Justin. 1980. Worthless, valuable or what? An appraisal of wetlands. Journal of Soil and Water Conservation, January-February: pp. 12-16.

Canada Department of Agriculature. 1974. The system of soil classification for Canada. Publication No. 1455. Ottawa, Ontario.

Cowardin, Lewis M. 1982. Wetlands and deep water habitats: A new classification. Journal of Soil and Water Conservation, March-Apil: pp. 83-85.

Eilers, R.C. 1973. The relationship between hydrogeology and soil characteristics near Deloraine, Manitoba. Master Thesis, Universiy of Manitoba.

Lissey, A. 1968. Surficial mapping of groundwater flow systems, with application to the Oak River Basin of Manitoba. A PhD. Thesis, Department of Geological Studies, University of Saskatchewan, Saskatoon, Saskatchewan: 106 p.

Meyboom, P. 1962. Patterns of groundwater flow in the paririe profile. Proceedings of Hydrology Symposium No. 3, Groundwater. November 8-9, University of Alberta, Calgary: pp. 5-17.

Meyboom, P. 1966. Unsteady groundwater flow near a willow ring in hommocky morain. Journal of Hydrology 4: PP. 33-62.

Meyboom, P. 1967. Mass-transfer studies to determine the groundwater regime of permanent lakes in hummocky moraine of western Canada. Journal of Hydrology, 5: pp. 177-143.

Millar, J.B. 1976. Wetland classification in western Canada. Canadian Wildlife Service, Report Series Number 37: 38 pp.

Pawluck S. 1973. Groundwater as related to solonetzic soils, in Solonetzic soils technology and management. Bulletin B-73-1, University of Alberta, Edmonton, Alberta.

Petsnik, J. 1975. Background information for the development of guidelines for prairie pothole drainage. Information paper, Water Resources Branch, Manitoba. Department of Mines, Resources and Environmental Management.

Rennie, D.A. and J.G. Ellis. 1978. The shape of Saskatchewan. Saskatchewan Institute of Pedology. Published M41. University of Saskatchewan, Saskatoon, Saskatchewan.

Rozkowski, A. 1967. The origin of hydrochemical patterns in hummocky moraine. Canadian Journal of Earth Science. Volume 4: pp. 1065-1092.

Sloan, Charles E. 1970. Biotic and hydrologic variables in prairie potholes in North Dakota. Journal of Range Management 23(4): pp. 260-263.

Stewart, Robert E. and Harold A. Kantrud. 1972. Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmetal factors; Hydrology of prairie potholes in North Dakota. Geological Suevey professional paper 585-D, prepared by the U.S. bureau of Sport Fisheries and Wildlife in collaboration with the U.S. Geological Survey, U.S. printing office, Washington, D.C. 36 p.

Toth, T. 1966. Mapping and interpretation of field phenomina for groundwater reconnaissance in a prairie environment. Alberta, Canada. Contribution 332, Research Council of Alberta, Edmonton, Alberta, Canada. pp. 1-49.

IMPACT OF AGRICULTURAL DRAINAGE ON WILDLIFE

Western Provincial Conference on
Soil and Water Management

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ABSTRACT

Canada's wildlife resources have a substantial economic value and 80 percent of all Canadians desire to see wildlife populations maintained. Prairie wildlife are dependent on wetlands. Wetland complexes that provide for the entire life cycle of wildlife must be preserved if this important economic resource is to be sustained. Wetlands in their natural state provide tangible benefits to agriculture and society. Drainage not only eliminates these benefits but can result in disbenefits. Present land management practises promote the indiscriminant drainage of wetlands. Wetlands are being destroyed at a rate of 18 percent per year. During the past 15 years mallard ducks have declined at a rate of 19 percent per year. Land management practises not only result in drainage, but wetland margins are being altered at an alarming rate. In Saskatchewan, critical habitat and the white-tailed deer herd have declined by 50 percent during the past 15 years.

Current water management policy and programs are geared to facilitate drainage and reclaim lands for agricultural purposes. This approach does not consider the dependency of other important industries on our soil and water resources. Canada needs comprehensive land and water management programs that reflect the needs and objectives of all Canadians.

INTRODUCTION

We are extremely pleased to have an opportunity to interact with the agricultural community on a subject of mutual concern, the impact of agricultural drainage.

First, we should state that agriculture and wildlife scientists share many views with respect to soil and water conservation. We also seem to share certain frustrations with respect to bringing resolution to problems relating to improved management of our prairie soil and water resources.

During the past two days we have discussed issues associated with managing water in our arid prairie environment. We will now focus on some disbenefits that drainage and wetland reclamation projects have on the wildlife industry, an industry as dependent on wise soil and water management as agriculture.

We will examine the economic and social value of wildlife to all Canadians and specifically to prairie residents. Next, we discuss the importance of wetlands to wildlife, to agriculture and to society. We present data on rates of wetland degradation and discuss implications to prairie wildlife. We outline social pressures and economic incentives for altering wetlands. Finally, we review the traditional role of wildlife agencies with respect to land-management and suggest methods of initiating cooperative multi-agency efforts for optimizing the benefits from soil and water management.

I. VALUE OF WILDLIFE

Wildlife have a substantial value and beneficial impact on Canadian society in terms of contributions to the national economy, outdoor recreation, aesthetic value, travel and tourism. In 1981, for example, Canadians spent 4.2 billion dollars on various wildlife related activities (Filion et al. 1983). Non-consumptive uses of wildlife accounted for 2.1 billion dollars and hunting accounted for 1.2 billion dollars.

The same study found that 80 percent of Canadians felt it was important to maintain abundant wildlife populations.

From a regional standpoint, the utilization of wildlife resources represents an important economic industry. The yearly expenditure on wildlife in 1981 was 592 million dollars in Manitoba, 715 million dollars in Saskatchewan and 863 million dollars in Alberta (Filion et al. 1983).

Wildlife cause some economic losses in terms of stock and produce depredations. Loss of cereal grains by waterfowl represents the most serious disbenefit in prairie Canada.

The benefits associated with waterfowl greatly outweight the costs. The annual costs of crop damage prevention, compensation, the value of uncompensated crop losses, public costs of management plus the cost of bird strikes to airplanes average 24.9 million dollars (Filion and Parker 1984). The revenues accrued from migratory bird hunting, however, are ten-fold the annual expenditures. In 1981, for example, 231.2 million dollars were expended hunting waterfowl (Filion et al. 1983).

Many more farmers enjoy waterfowl than the number of farmers that sustain crop losses. The number of crop damage claims filed in prairie Canada average 2280 between 1978 and 1981 (Poston in prep.). Filion (1978) stimated that 15 percent of prairie waterfowl hunters live on farms. For example, in 1981, 900 claims were filed whereas approximately 22,000 of our 150,000 prairie waterfowl hunters resided on farms.

The relationship between wildlife and farmers is often oversimplified. Rather than labelling species as good or bad it would be more useful to implement effective management programs that take advantage of their attributes while minimizing their negative effects. The federal government and prairie provinces have developed crop damage prevention and compensation programs to offset the negative effects of waterfowl. We are optimistic that the responsible agencies can implement effective means for alleviating this problem to everyone's satisfaction.

Canada, and prairie Canada in particular, is blessed with an abundance of wildlife, but it is, in some ways, a mixed blessing. The apparent bountiful supply has spawned an attitude that wildlife resources are unlimited, free goods. This of course is not true. Wildlife require food, water and shelter. In prairie Canada this public resource is sustained primarily on private land. This brings us to the subject at hand: the drainage of wetlands. Drainage that might lead to increased revenue to individual landowners, but will have a detrimental impact on wildlife populations, the wildlife industry and perhaps the farmers themselves.

II. VALUE OF WETLANDS

A. VALUE OF WETLANDS TO WILDLIFE

Wetlands represent an important component of the prairie ecosystem. They are essential to the survival of the wildlife forms that have evolved in or adapted to the prairie environment.

Prairie wetlands vary in size, depth, permanency and vegetative composition, however, they have one common feature: they are highly fertile. Wetlands support an abundance of plants and animals and provide food, water and shelter to nearly every species of prairie wildlife. Some 160 species of birds and 50 species of mammals are dependant on prairie wetlands (Siegfried 1982). The values of wetlands to animals such as waterbirds, muskrats, fish and amphibians are obvious. Wetlands are also extremely important, in a less obvious way, to other species such as white-tailed deer (Sparrowe 1966) and upland game birds (Gates and Hale 1974).

Drainage of wetlands does not provide one tangible benefit to wildlife. The question then becomes, are certain types of wetlands more critical to wildlife than others? Some farmers tell us that big sloughs should be left for wildlife, but small ones usually dry-up in mid-June so they should be drained. Wildlife habitat preservation programs generally emphasize preserving large waterbodies. These large, permanent sloughs generally are not susceptible to drainage and may be available to wildlife agencies by default. The practise of focusing solely on large waterbodies, however, has three disbenefits. Firstly, these areas are generally not highly productive, and secondly, developing large permanent waterbodies for migratory birds often concentrates waterfowl in the autumn. This can result in, or accentuate crop damage problems. A third disbenefit is that focusing on large permanent wetlands can result in losing smaller and equally valuable ponds.

We do not mean to infer that large marshes are unimportant to wildlife, but rather that wetland complexes, including temporary, semipermanent and large wetlands are critical to the life cycle of most wildlife forms.

Let's examine the wetland complex approach as it applies to prairie ducks. We focus on ducks for three reasons: ducks and duck hunting represent an important economic industry in prairie Canada; the Canadian prairie pothole region produces up to 70 percent of North America's game ducks; and ducks are highly visible users of wetlands and therefore, serve as good "indicator species".

The basic requirements of prairie ducks include food, water, space, and facilities for nesting, brood-rearing, molting and staging. No one type of slough adequately provides all of these needs, however, all requirements are furnished by the variety of sloughs found in a typical prairie wetland complex.

Breeding ducks, like domestic fowl, require high protein diets during egg laying. Protein and calcium requirements are met by feeding on aquatic invertebrates which may constitute 99 percent of the diet of egg laying hens (Swanson et al. 1979). Access to aquatic invertebrates comes through foraging in shallow wetlands.

Upon their return from the wintering grounds, breeding ducks are attracted to areas featuring high densities of small, ice-free, temporary ponds. These temporary ponds are generally shallow basins containing run-off snow melt. The shallow fertile water is readily heated and is soon teeming with aquatic invertebrates. Temporary ponds also provide an abundance of loafing sites for pairs. They are usually dry by mid- to late June, however, they provide a vital source of nutrients to early nesting ducks. Their dry basins are often later utilized as nest-sites.

Deeper, semipermanent ponds are also important to breeding ducks. They are usually less than three feet deep and feature perennial emergent and submergent aquatic vegetation. They persist throughout the breeding season during years of average precipitation, but dry-up during drought. Aquatic invertebrates become readily accessible as water levels recede. Semipermanent ponds provide food and nest-sites to breeding ducks. They also provide food, water and cover for duck broods.

Permanent sloughs and lakes may not be as important for breeding to most species of prairie ducks, but are used extensively for post-breeding activities. They provide cover and protection from land predators during the flightless molt period. They are also important as staging areas during spring and autumn. In addition to these functions, large waterbodies receive extensive use during drought years.

We would like to stress that the variety of wetlands found on the prairies is what makes this habitat so productive. Temporary ponds, ideal for use by breeding pairs, are often dry by brood-rearing time. Semipermanent ponds, less suitable at the onset of nesting, subsequently provide food and shelter for broods. Large marshes provide important post-breeding facilities. Thus, good waterfowl habitat must include diverse wetland types to meet the needs of birds throughout the breeding season (Sugden 1984). The same principle applies to the needs of other wildlife species.

B. VALUE OF WETLANDS TO AGRICULTURE

Wetlands are vital to prairie wildlife. Although we believe that the social and economic arguments we offer are sufficient justification for preserving wetlands, in reality, wetland complexes will not be sustained unless the Canadian public is convinced that wetlands are vital to the national interest. Therefore, we would like to pursue the thesis that wetlands should be preserved, not solely for wildlife, but for the values they provide to the agricultural industry, to farmers and to the general public.

We are not experts in the agricultural field. We offer a list of benefits that we have gleaned from the literature. The list is our interpretation of conclusions reached by others, including agronomists, soil scientists and farmers.

We understand that wetlands provide at least ten tangible benefits to agriculture. (1) Wetlands benefit agriculture through moisture retention. They trap snow, store run-off, recharge ground water and contribute to potable water supplies. (2) Wetlands moderate our arid climate by providing millions of acres of surface area for evaporation, transpiration and eventually, precipitation. (3) They can provide benefits relative to confining salinity. (4) They provide a source of water for livestock. (5) Wetlands provide a source of fodder during dry years. High quality forage can be fed to livestock or sold during periods of limited hay supplies. (6) Wetlands contain a variety of vertebrates and invertebrates that provide biological control of weeds and agricultural pests. These include insectivorous and seed eating birds, parasitic and predatory invertebrates which benefit agriculture. (7) Undisturbed wetlands have stable perennial plant communities. Drained and disturbed basins facilitate outbreaks of annual weeds. (8) Wetlands store run-off and prevent flooding of lower-lying fields. (9) Wetlands play a role in reducing soil erosion. (10) Wetlands furnish a source of water that can be used for agricultural purposes including irrigation and tank-mixing sprays.

We reitorate that we are not hydrologists nor agronomists but biologists. We believe, however, that wetlands possess values that must be incorporated in water management programs. In prairie Canada, as we were reminded in 1984, water is our most precious resource. Moisture is the single most important factor limiting crop production. Logically, land and water management practises should reflect an effort to capture and store precipitation for utilization during both current and future years (Zittlau 1979).

C. VALUE OF WETLANDS TO SOCIETY

In addition to serving wildlife and agricultural interests, wetlands provide values to society. Furthermore, drainage often causes disbenefits to society.

The benefits include: (1) flood control; (2) trapping and consolidating sediments; (3) breaking down organic pollutants; (4) industrial values, including trapping and trout farming; (5) recreational values, including swimming, boating and skating; and (6) aesthetic values. These features must be considered before public funds are allocated to drainage.

III. THE PROBLEM: INDISCRIMINANT DRAINAGE

A. INCENTIVES TO DRAIN WETLANDS

Why do farmers drain wetlands? Factors promoting wetland drainage include an increased demand for goods, ready markets, rising production costs, the need to increase farm efficiency as well as provision of government subsidies.

There are some 20 acts and policies dealing with water control in the prairie provinces. The overriding principle governing this legislation is the facilitation of wetland drainage. The objectives and scope of water policy in the prairies may be short-sighted. Costs for drainage on public lands are paid by the people of Canada: drainage costs on private land are also subsidized by the Canadian public, both in terms of direct financial support and indirectly by tax deductions. It is paradoxical that 80 percent of the Canadian public wish to maintain wildlife populations, yet enormous amounts of public funds are utilized for eliminating wildlife habitat on both public and private lands. Conversely there are few economic incentives for preserving wildlife habitat, even on lands with low agricultural capability. In essence, the existing legislation that governs land use penalizes landowners for preserving wildlife habitat.

Perhaps the most important policy influencing land and water management pertains to regulations governing the Wheat Board quota system.
Wheat Board regulations stipulate that land, in order to qualify for delivery quota, may not be in a native or wild state, but must have been "improved" by cultivation (Zittlau 1979). Lands with low agricultural capability, including wetlands, woodlots and pasture are broken, often not to grow more food, but to increase the quota acreage.

The quota eligible improved acreage has increased by 8.6 million acres in prairie Canada since 1976. Much of this land was of little agricultural potential. The primary objective of conversion was to increase quota entitlement (Zittlau 1979).

The Canadian Income Tax Act encourages agricultural utilization of marginal land, including wetlands, through taxation policies governing non-productive land. There are no deductions for preserving native lands that are necessary to the wildlife industry and have considerable value to society and to the Canadian economy. There are deductions available for destroying such wild areas. For provincial property tax purposes, rural lands are classified as cultivated, pasture or wasteland. The term wasteland has a negative conotation. Tax notices do not reflect the rate of taxation for the various classes of rural land. The tendancy is to average that total tax burden over total acres. Understandably, there arises an incentive on the part of the landowner, to make residual "wasteland" bear some of the economic burden associated with it (Zittlau 1979).

Various government agencies, even within departments have conflicting land-use objectives. While some promote soil, water and wildlife conservation, often other branches with much larger budgets, provide low interest loans, grants and technical assistance for "improving" native lands (Cowan 1982). In general, government policies promote intensive land use without regard for soil and moisture conservation. Farmers and local governments receive incentives to seek financial return on every acre. There is little if any financial incentive to promote soil and moisture conservation let alone preserve lands for wildlife. Farmers cannot afford to leave native lands for wildlife.

B. RATES OF WETLAND LOSSES

Drainage of prairie wetlands has followed a pattern. Most of the readily drainable large wetlands in the black soil zone were drained before 1950 (Goodman and Pryor 1972). More recently with the advent of larger farm equipment, temporary and semipermanent ponds are being drained. In Manitoba, for example, more than 60 percent of the wetlands were drained on one study area between 1930 and 1970 (Kiel et al. 1972). Since 1970 the wetland area on this study area has been further reduced by 56 percent (Rakowski and Chabot 1983). On a southern Saskatchewan study area, 27 percent of the wetlands were destroyed (Millar 1981). In Alberta's aspen parkland, 61 percent of the wetland area was lost by 1970 (Schick 1972).

Drainage rates are alarming and accelerating. Surveys conducted by the Canadian Wildlife Service indicate that drainage, filling and cultivation of semipermanent and permanent wetlands is presently occurring at a rate of 18 percent per year across the western prairie provinces. Our data indicate that the rate of wetland destructions is highest in southern Saskatchewan (21 percent), followed by southern Alberta (13 percent) and southern Manitoba (11.5 percent). We speculate that farming traditions are such that considerable drainage has already occurred in Manitoba and Alberta and the higher rate in Saskatchewan represents a "catch-up" situation rather than more moderate drainage practises in the other two provinces.

In addition to these permanent losses of wetlands, our data indicate that other intensive farming practises are having a significant impact on remaining wetlands. A study of all agricultural land-use practises (burning, clearing, grazing, cultivating, mowing, filling and drainage) showed that 61.4 percent of wetland margins were detrimentally impacted by these activities. Our interpretation of these data is that the high rate of impaction in Alberta (87 percent) is correlated with the drought that has occurred since 1976. The impaction rate of 59 percent in Saskatchewan reflects the all-out intensification of "clean-farming" practises that are presently underway: Saskatchewan is in a transitional state. Manitoba's slower rate of impaction (48 percent) indicates that many cf their wetlands have already been destroyed. Time trend analyses of these data indicate that the rate is accelerating (Brace on Caswell 1984).

Uncultivated marginal lands including shelter belts, fence rows, woodlots, brushy streambanks, overgrown road allowances, pastures and prairie potholes provide food, shelter and living space that are essential to prairie wildlife. Agricultural activities that result in clearing marginal lands are having a devastating impact on prairie wildlife populations. For example, southern Saskatchewan's white-tailed deer herd has declined by 50 percent during the past 15 years. This is concurrent with a loss of 50 to 60 percent of critical wildlife habitat over the same period. Furthermore, habitat on private land is continuing to be lost at a rate of up to 5 percent a year.

Prairie duck populations have also undergone dramatic population declines during the past 15 years. The phenomenal growth of the agricultural industry and intensified land use has paralleled declining duck populations. For example, mallard ducks, our principle game bird species, are currently at all time lows throughout prairie Canada. Mallard populations have been declining at a rate of 19 percent per year since 1970 (Brace and Caswell 1983).

Mallard production has declined dramatically during the past 15 years (Hochbaum and Caswell 1978). Habitat destruction, including loss of wetlands, have resulted in a loss of suitable nesting sites as well as changes in predator communities. Mallards are presently forced to nest in sub-optimal areas where predators easily find and destroy their nests. For example, in the Minnedosa area of southern Manitoba, 40 percent of female mallard hens successfully reared broods during the mid 1950's. The current mallard hen success rate is 19 percent for southwestern Manitoba (Hochbaum and Caswell 1978). Hen success rates have fallen similarly in southeastern Saskatchewan and southeastern Alberta.

Wetland and associated upland habitat is being lost at an alarming rate. The loss of this critical habitat is having a predictable, negative impact on prairie wildlife resources. This in turn is limiting our ability to accrue positive benefits from our wildlife resources in terms of recreation and economics.

Natural resource agencies hope to sustain the wildlife based industries. Agriculturalists look to increasing the production of cereal grains. It is imperative that we determine mechanisms by which those two aims are jointly possible.

IV. THE SOLUTION: AN INTEGRATED APPROACH

A. THE ROLE OF WILDLIFE AGENCIES

Traditionally, public and private wildlife organizations have been hampered in their ability to secure and manage wildlife habitat. Relatively small budgets and a low public profile have limited habitat retention options. Projects have been mainly opportunistic, capitalizing on securing large permanent wetlands and ignoring the more vulnerable smaller ones. Wildlife agencies have not had the luxury of practising a wetland complex approach and our wildlife resources have suffered. The inability to exert horizontal influence within government has hamstrung wildlife agencies. This is particularly evident in land-use conflicts where issues are complex and wildlife managers positions appear inflexible, "game" oriented and unresponsive to changing social and economic conditions (Neave 1984).

The relative amount of time that industry, land-use agencies and government wildlife agencies devote to policy development, reacting to policy, and monitoring impact of policy relative to industrial operations was recently examined (Neave 1983). Quantifying these activities revealed that unlike industry and land-use agencies, wildlife departments devote little time to policy development. Wildlife agencies also spend little effort on monitoring, which in this study included extension, education and application of policy. Instead wildlife agencies expend the majority of their time and effort on referrals, which in this analysis meant carrying out environmental impact studies and reacting to policy. "This regulatory approach has dampened efforts of resolving conflicts with other resource sectors and has provided us with an antagonistic image to politicians and industry" (Neave 1984).

This approach to managing wildlife has not worked. Wildlife populations are declining and a resource of proven public value is being lost as a result of current soil and water practises. The perlious status of many species is causing a ground swell in public opinion. There is suddenly more media coverage, more public and political concern about wildlife. The demands the public are placing on wildlife organizations are changing and the role of wildlife agencies must respond to meet these expectations. Wildlife Agencies must accept their responsibilities, and work cooperatively with other land management agencies to ensure that wildlife values are incorporated in land-use decisions.

Wildlife agencies should and can play an active role in soil and water conservation. Wetlands are important to wildlife, to agriculture and to society and wildlife agencies have a moral responsibility to ensure that these values are considered in policies and programs that govern prairie soils and water.

B. A PROPOSED PRAIRIE WATER MANAGEMENT SCHEME

What constructive role can wildlife agencies play with respect to soil and water conservation? We do not have the final solution, but what brings us here are the same factors that bring you here. We have been educating each other over these 3 conferences as to man's needs and the affects of soil and water management. Agriculture has problems with the use of soil and water resources: so does wildlife.

At the outset we discussed shared frustrations with respect to implementing sound soil and water management programs. At this point in time there are enough agencies dependent on our land concerned over soil and water management to implement an effective utilization program. The problems are of sufficient magnitude that there now exists the critical mass required to affect a solution. Let us strive to develop a mutually acceptable solution to some common problems.

We offer the following simplistic water management approach, not as a final solution, but as a template, which soil and water resource agencies might use to improve the utilization of our shared resources.

The first step is to develop a forum that would include all agencies dependant on soil and water resources. Such a forum is needed to assess and plan land-use practises. This conference represents an example of multi-agency consideration of major soil and moisture problems. The Standing Senate Committee on Agriculture, Fisheries and Forestry represents another attempt at developing an integrated approach. The political will to resolve soil and water problems exists. What is needed is a mechanism for pulling together the technical expertise from the various sectors. Recommendations that reflect a common position could be jointly forwarded and appropriate policy could result.

Second, goals and objectives need to be defined. These need to consider all aspects of soil and water management, including drainage, flood prevention, drought prevention, wildlife values, etc.

Next, there is a need to define the magnitude of the resource base. Several inventories have been conducted in the past and it may be possible to utilize existing information.

Fourth, after the goals and objectives have been developed and the magnitude of the resource base is known, a comprehensive long-range multiple-use plan for wetlands and land management should be developed.

The plan would, among other things, establish a protocol for utilizing wetlands. It would determine which wetlands are vulnerable and which are secure. Rules would need to be established to regulate the utilization of numbers and types of wetlands.

Public institutions that promote indiscriminant drainage of wetlands should be amended. Sawatzky (1984) in his presentation to the Standing Senate Committee on Agriculture, Fisheries and Forestry outlined procedures for improving the Wheat Board Quota and land taxation systems. At present there are financial incentives offered to landowners encouraging destruction of wetlands but little if any remuneration for maintaining them. Public funds should be made available to offer alternatives. There are presently major initiatives underway in this area in the form of Habitat Canada. Furthermore, the Canada-United States Waterfowl Management Plan, presently being developed, could potentially generate many millions of dollars for the preservation of wetlands. These and similar funding opportunities could be incorporated into the long-range multiple-use program.

Finally, the probability of implementing a successful multi-agency land-use program will be dependent on the size of the sector which understands and approves what you are doing. Public education and consultation are important ingredients of the proposed initiative. The concerned agencies need to develop and promote a sensible resource utilization scheme that is in the best interests and has the support of all aspects of the Canadian public.

The foregoing discussion plan is intended to be general and flexible. The essential element is future land-use exercises and programs must consider the needs of all segments of Canadian society. To continue to implement land-use proposals that benefit only one sector and harm others is unacceptable. By combining our experience and wisdom and facilitating all of our needs we will have a better probability of sustaining our soil and water resources for the short and long-term benefit of all Canadians.

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LITERATURE CITED

Brace, R.K. and F.D. Caswell. 1984. Prairie Waterfowl Status Report: A Briefing Document. Unpubl. CWS Rept. 11 pp.

Brace, R.K. and F.D. Caswell. 1983. Prairie Waterfowl Status Report: A Briefing Document. Unpubl. CWS Rept. 20 pp.

Cowan, W.F. 1982. Breeding habitat competition on every hand: Agriculture. Unpubl. DU Rept. 18 pp.

Filion, F.L. and S.A.D. Parker. 1984. Human dimensions of migratory gamebird hunting in Canada. CWS Occas. Paper 51, Ottawa. 34 pp.

Filion, F.L., S.W. James, J.L. Ducharme, G.W. Pepper, R. Reid, P. Boxall, and D. Teillet. 1983. The Importance of Wildlife to Canadians. CWS Rept. No. CW66-62/1983E. 40 pp.

Gates, J.M. and J.B. Hale. 1974. Seasonal movement, winter habitat use, and population distribution of an east-central Wisconsin population. Wisconsin Dept. Nat. Resour. Tech. Bull. No. 76. 56 pp.

Goodman, A.S. and S.P. Pryor. 1972. A preliminary study of the methods and rates of alteration of waterfowl habitat in the black soil zone of western Canada. Unpubl. Rept. CWS. 77 pp.

Hochbaum, G.S. and F.D. Caswell. 1978. Forecast of long-term trends in breeding mallard populations on the Canadian Prairies. CWS Prog. Note No. 90. 8 pp.

Kiel, W.H. Jr., A.S. Hawkins and N.G. Perret. 1972. Waterfowl habitat trends in the aspen parkland of Manitoba. Can. Wildl. Serv. Rep. Ser. 18. 61 pp.

Millar, J.B. 1981. Habitat changes in Saskatchewan waterfowl strata 30 to 33 between fall 1978 and fall 1980 - Prairie Waterfowl Habitat Evaluation Program. CWS Unpubl. Rept. 60 pp.

Neave, D.J. 1984. Out clients and their changing expectations "Wildlife Habitat Canada and other Approaches". Unpubl. Rept. Presented to International Fish and Game Commissioners, Victoria. July 1984. 10 pp.

Poston, H.J. In Prep. An assessment of programs for alleviating crop damage by waterfowl in prairie Canada. CWS Unpubl. Rept.

Rakowski, P.W. and B.P. Chabot. 1983. Changes in land use in the Minnedosa district of southwestern Manitoba: An update on the Kiel-Hawkins transects. Unpubl. CWS Rept. 10 pp.

Sawatzki, L. 1984. Presentation to the Standing Senate Committee on Agriculture, Fisheries and Forestry 2nd Session of 32 Parliament, 1983-84, Issue No. 6 Pp. 81-85.

Schick, C.D. 1972. A documentation and analysis of wetland drainage in the Alberta parkland. Unpubl. CWS Rept. 15 pp.

Siegried, R. 1982. Wetlands: Future Environmental Barometer. In Naturalist, Natural History Society, Minneapolis, Minnesota. Pp. 14-15.

Sparrowe, R.D. 1966. Population distribution and mobility of deer in eastern South Dakota. M.S. Thesis. South Dakota State Univ., Brookings. 81 pp.

Sugden, L.G. 1984. The Waterfowl Resource of the Canadian Plains. In Prairie Forum, 1984, 9(2):299-314.

Swanson, G.A., G.L. Krapu and J.R. Serie. 1979. Foods of laying female dabbling ducks on the breeding grounds in Waterfowl and Wetlands - An Integrated Review. Proc. 39th Midwest Fish and Wildl. Conf., Madison, Wisconsin.

Zittlau, W.T. 1979. An environmental assessment of agricultural practises and policies: implications for waterfowl habitat management. Natur. Resour. Inst., Univ. Manitoba, Winnipeg. 282 pp.

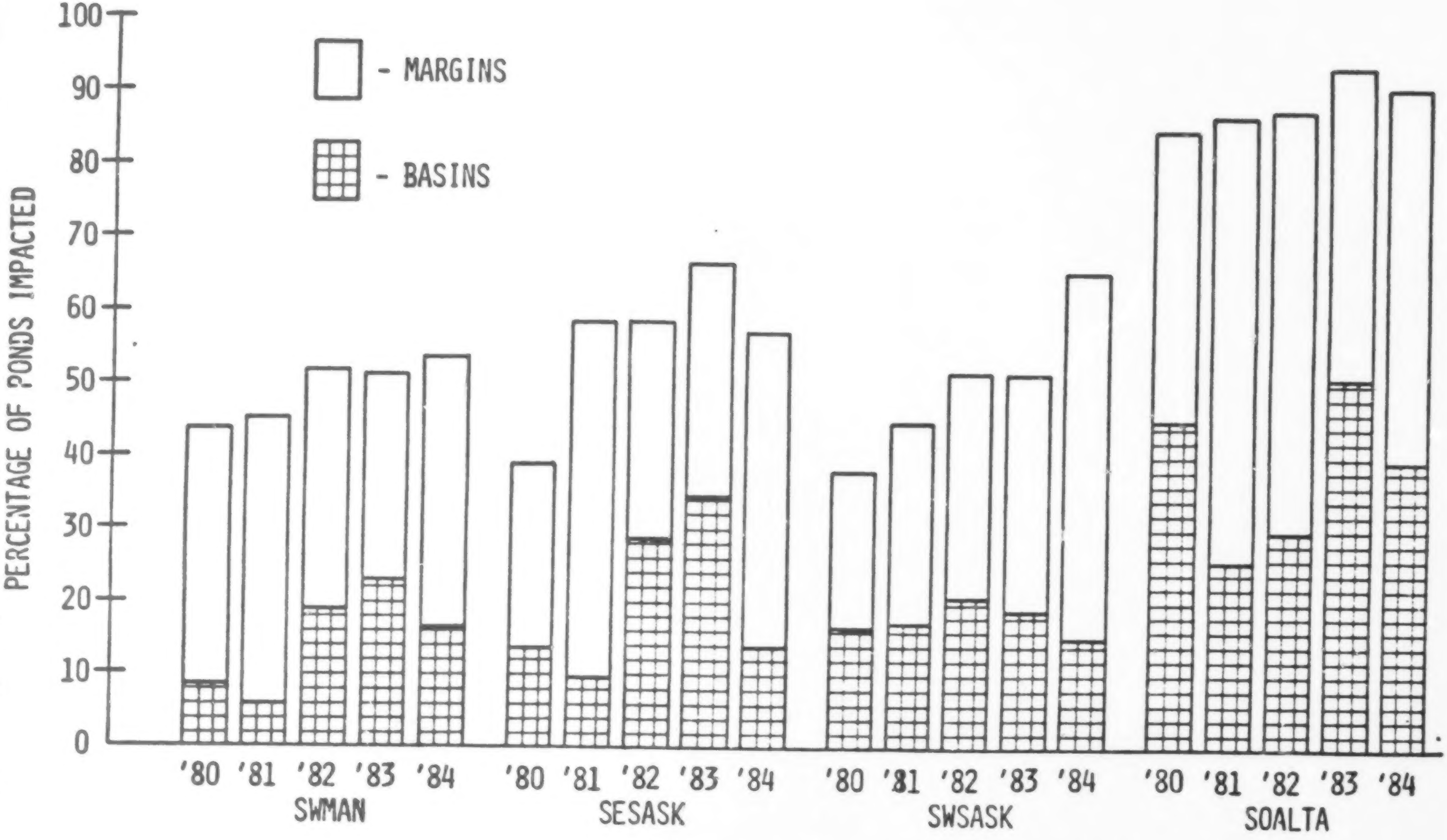

FIGURE 1. AGRICULTURAL IMPACTIONS ON PONDS IN PRAIRIE CANADA FROM 1980 TO 1984

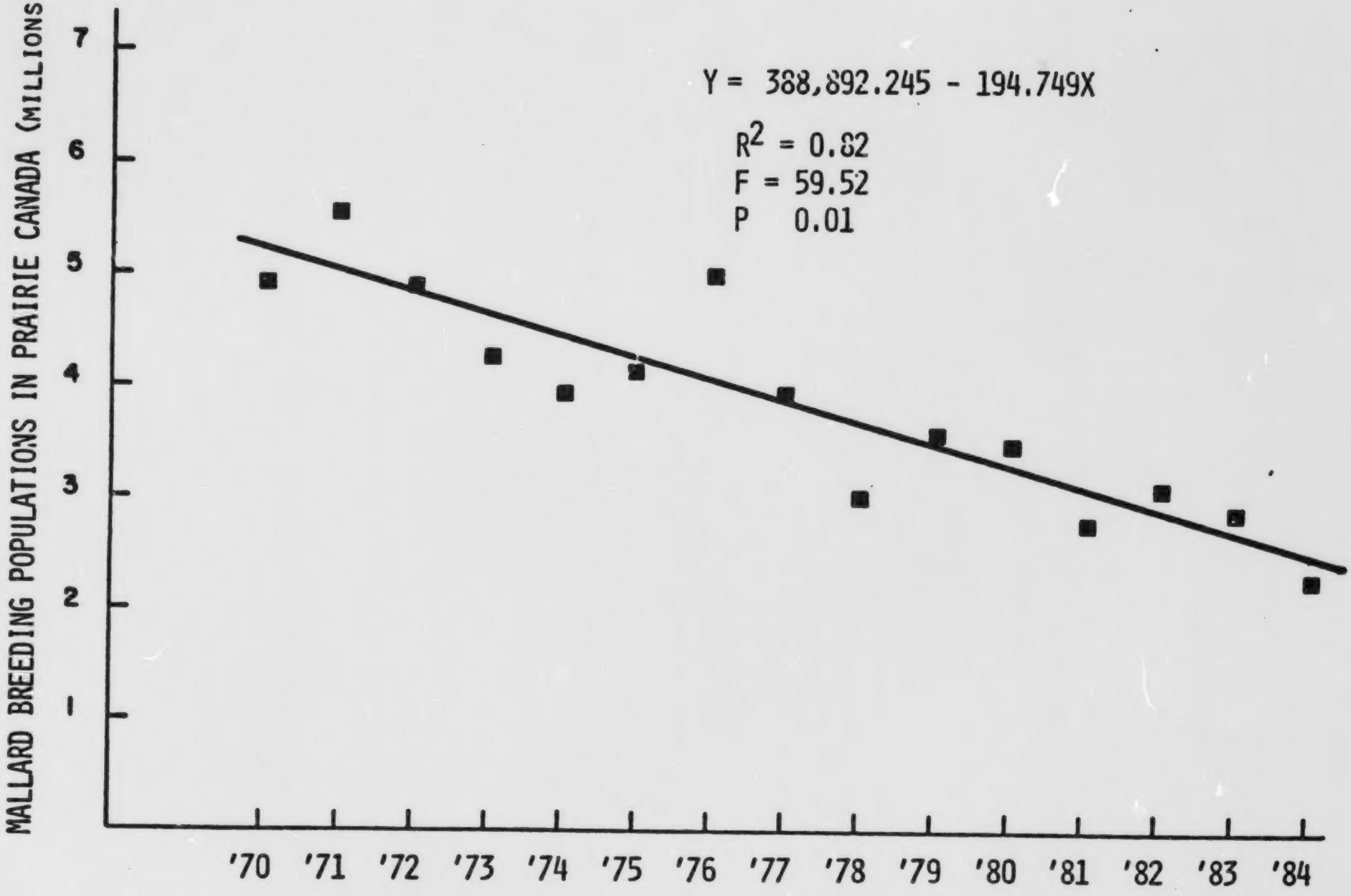

FIGURE 2. TRENDS IN MALLARD BREEDING POPULATIONS IN THE PRAIRIE REGION OF CANADA

EXPENDITURES BY CANADIANS ON WILDLIFE RELATED ACTIVITIES, 1981.

NON-CONSUMPTIVE USES	$2.1 BILLION
HUNTING	$1.2 BILLION
OTHER	$0.9 BILLION
TOTAL	$4.2 BILLION

(After Filion et al., 1983)

WILDLIFE RELATED EXPENDITURES IN THE PRAIRIE PROVINCES, 1981.

	ANNUAL EXPENDITURE
MANITOBA	$592 MILLION
SASKATCHEWAN	$715 MILLION
ALBERTA	$863 MILLION
TOTAL	$2.17 BILLION

COMPARISON OF NUMBER OF MIGRATORY BIRD HUNTERS LIVING ON FARMS TO NUMBER OF CROP DAMAGE CLAIMS, 1981.

	NO. RESIDENT HUNTERS	NO.[1] FARMER HUNTERS	NO.[2] DEPREDATION CLAIMS
MANITOBA	40,098	6,015	346
SASKATCHEWAN	39,118	6,000	303
ALBERTA	65,033	9,755	251
TOTAL	144,249	21,770	900

[1] Calculated after Filion, 1978.

[2] After Poston, in preparation.

PERCENTAGE OF SEMIPERMANENT AND PERMANENT WETLANDS, DRAINED, FILLED AND CULTIVATED, 1981-1983.

	PERCENTAGE WETLANDS LOST	CURRENT RATE OF WETLAND LOSS
MANITOBA	60 (1930-1970)[1] 56 (1970-1983)[2]	11.5%[5]
SASKATCHEWAN	27[3]	21.0%
ALBERTA	61[4]	13.0%
PRAIRIE PROVINCES		18.0%

1. Kiel et al., 1972.
2. Rakowski and Chobot, 1983.
3. Millar, 1983.
4. Schick, 1972.
5. CWS Survey Results.

PERCENTAGE OF SEMIPERMANENT AND PERMANENT WETLAND. MARGINS IMPACTED BY AGRICULTURAL LAND-USE PRACTISES, 1981-83

	IMPACTED MARGINS
MANITOBA	48%
SASKATCHEWAN	59%
ALBERTA	87%
PRAIRIE PROVINCES	61.4%

(CWS SURVEY RESULTS)

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PRAIRIE POTHOLES AND THE PRAIRIE FARMER*

by

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Abstract

The most controversial land managment issue in the prairie pothole region of North America continues to be the drainage of wetlands. Most prairie wetland drainage is done by farmers following economic signals sent by the marketplace. The controversy arises because most of the benefits of undrained prairie wetlands accrue to persons other than the wetland owner. The economics of this controversy revolve around the clash of public vs. private goods and the assignment of property rights. Private market incentives to drain include increased crop production, increased land values, and more efficient use of farm equipment. Public nonmarket preservation values include wildlife habitat, floodwater retention, landscape diversity, and other recreational and amenity values. A balance needs to be drawn between these conflicting perspectives. Neither wetland use option--preservation or drainage--can be shown to be superior across-the-board.

Prepared for presentation at the Third Annual Western Provincial Conference on Agricultural Land Drainage, November 20-22, 1984, Winnipeg, Manitoba.

PRAIRIE POTHOLES AND THE PRAIRIE FARMER

Jay A. Leitch*

The most controversial land management issue in the prairie pothole region of North America continues to be drainage of wetlands. Most prairie wetland drainage is done by farmers following the economic signals sent by the marketplace. The controversy exists because benefits of undrained wetlands accrue to persons other than the wetland owner. Farmers are acting in their own best interests as are proponents of wetland preservation. Neither are "bad guys."

The purpose of this paper is to explain the landowner's position from an economic perspective, identifying some institutional mechanisms that may ameliorate the controversy.

The Issue

Prairie wetlands have been shown to have considerable value to society (Office of Technology Assessment 1984). At the same time individuals attempting to maximize returns to ownership of agricultural land cannot capture most of these social benefits. Therefore the incentive exists to drain wetlands for crop production. A study of excess water on better quality cultivated land in East Central Alberta indicated that over 20 percent of the land was in "sloughs and wetland" (Apedaile and Rapp 1983). One way to increase land farmed is to drain these wetlands, oftentimes a less expensive method than purchasing land without excess water problems.

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Landowner Alternatives

Private returns to wetland drainage have been discussed by others (Leitch and Kerestes 1981, Rigaux and Singh 1977) and are comprised mostly of sales of agricultural commodities. Since there are virtually no private market returns to wetlands preservation--by definition a "public good"--individuals will opt to produce agricultural commodities over wetlands.

Consider a case where an individual farmer is faced with producing either wetlands or agricultural commodities on a fixed amount of land. Theoretical options include producing all crops, all wetlands, or somewhere in between. This set of choices is depicted in Figure 1, where the x-axis represents potential output of crops given the fixed land resource, and the y-axis represents potential output of wetland on the same fixed amount of land.

The lines tangent to the production possibilities frontier (ab, cd, ef, and gh) represent selected trade-off relationships facing the resource owner between the two possible products. Since there are virtually no private market returns to wetlands and there exists well established markets for crops, line ab represents the situation as currently seen by most prairie pothole region farm operators. Line ab suggests that it is in the farm operator's best interest to produce all (Ox) crops and no wetlands.

If we assume the farm operator derives some market return or personal satisfaction from maintaining wetlands, the trade-off line may look like line cd. This could occur if the operator hunted or trapped in his wetlands, if his urban friends hunted the wetlands, or if he leased his wetlands to hunters. In each case the farm operator would be willing to give up some crop production (x^*x) for some wetlands (Oy^{**}) because he either received monetary incentives or personal satisfaction.

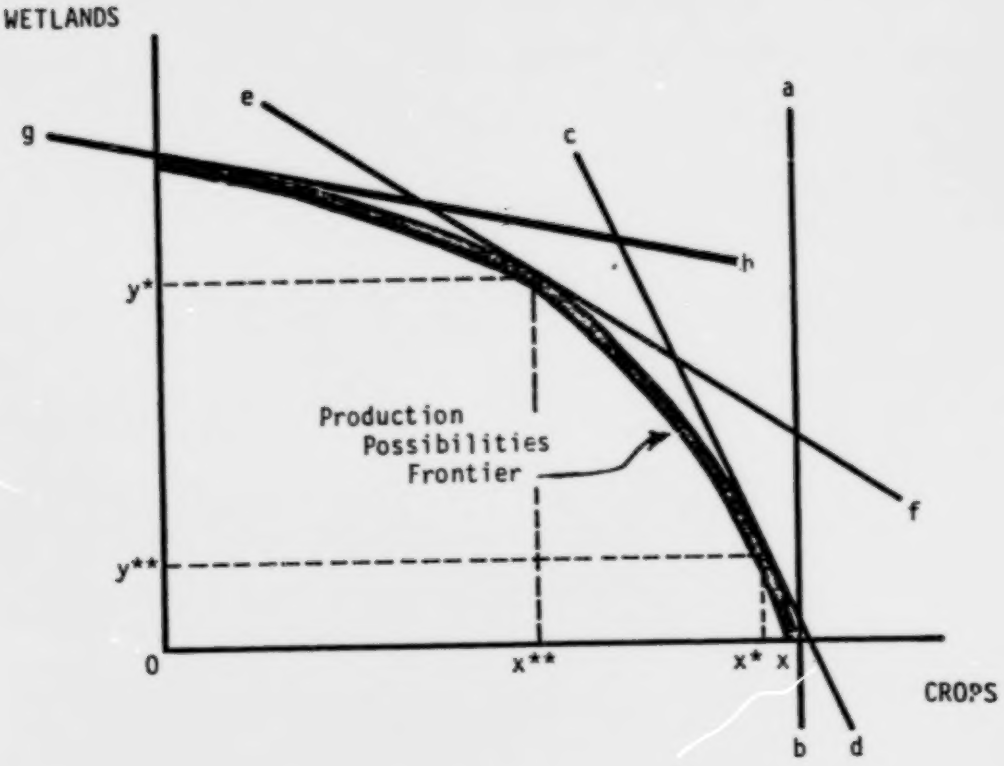
WETLANDS
g
e
c
a
h
y*
Production Possibilities Frontier
f
y**
0
x**
x*
x
CROPS
b
d

Figure 1. Alternative Levels of Outputs of Two Products With a Fixed Input--Land

Another possible scenario is if some private organization or government agency offered to pay the farm operator an amount similar to his return to farming to preserve wetlands. The trade-off line facing the landowner would be 45°, indicating a mix of wetlands and crop production. Line ef represents approximately equal returns--levels of satisfaction--to crop production and wetland maintenance.

A final scenario is if the farm opertor derived immense personal satisfaction from preserving wetlands or could elicit preservation payments greater than crop production returns. Line gh represents this trade-off relationship and implies the farm operator's rational, albeit unrealistic, option would be to produce all wetlands.

While these four scenarios are generalizations of real world conditions, they represent the forces, incentives, and alternatives, both market and nonmarket, facing farm operators in the prairie pothole region.

Landowner attitudes have been shown to be an extremely important factor in formulating successful wetland preservation policies (Smutko et al. 1984). Animosity toward government, hunters, and environmentalists tend to make the trade-offs favor the x-axis output (making crop production more attractive relative to wetlands preservation). Government programs to subsidize land drainage or agricultural production also make crops a more attractive use of the fixed land resource than wetlands. Pressures from financial institutions to maximize economic output from available resources skews the trade-off line toward vertical. Lenders do not appreciate debtors' satisfaction or social values derived from wetlands, only sales of agricultural commodities will repay loans. An extremely strong influence reducing the potential satisfaction from wetlands preservation is the nuisance factor. Wetlands become obstacles to farm around, especially with modern, large-scale farm equipment. Center pivot irrigation and wetlands preservation are also not compatible. Thus, while the nuisance is difficult to quantify it is a factor in the relative satisfaction received from the two posited outputs from the fixed land resource.

Policy Options

Incentives--monetary, moral, or legal--to increase wetland preservation on private lands change the trade-off relationships between wetlands and agricultural production (Figure 1).

Several policy measures have been suggested that would achieve higher levels of wetland preservation concomitant with maintaining farm operator satisfaction. There are four general types of public policy instruments: (1) market processes, (2) regulation, (3) social pressure, and (4) government provision (Table 2) (Baumol and Oates 1979).

TABLE 2. POLICY INSTRUMENTS

Type	Examples
Market Processes	Payments to producers
	Taxes on nonproducers
	Tax structure accommodation
Regulation	Prohibition
	Control by permit
Social Pressure	Public information campaigns
	Understanding attitudes
Government Provision	Research and technology change

Implementation and subsequent success of public policies to affect landowner decisions hinge on a number of related factors. Market incentives or subsidies work when money is available to provide incentives (e.g., Duck Stamp Program, Water Bank) and property rights are assumed to be held privately. Taxes and charges work when enforcement and measurement are feasible and property rights are held publicly. Stromstand (1983) argues property tax exemptions and credits could be successfully used to maintain prairie wetlands. Income tax provisions work well for other than marginal land management changes and where landowners have other than nominal tax obligations. Government regulation works when property rights are held de facto by society and enforcement is feasible. Social pressure (moral suasion) works in time of crises or where the issue is merely one of information shortages that can be ameliorated by education.

Public programs to preserve, conserve, or enhance wetland resources on private lands historically run the gamut from strict prohibition to monetary payments. Government programs to preserve wetland habitats have relied on economic incentives, regulation, and social pressure. The history of wetlands preservation typifies the changing public role in regulating amenity resources (Kusler 1983, Office of Technology Assessment 1984).

Parameters of these policy options are many dimensional. Society's interests in wetlands preservation are a primary factor. Yet little is known about the quantitative level of these values. Landowner rights and values need to be maintained. The economists' Pareto conditions should be met--a situation where no one should be made better off unless none are made worse off. In this case, if society's values are to be enhanced or maintained, it should not be at the expense of individual landowners' values.

Other Concerns

Wetlands preservation issues pervade many sectors of society. The argument and subsequent potential policy instruments surrounding trade-offs between wetlands and crop production revolve around individual landowner's rights and social values. A third affected sector is regional economies. Flows of goods and services, tax payments, and employment opportunities are each affected by shifts in land use from crops to wetlands or vice versa. Pareto optimality suggests the satisfaction of individuals, businesses, and other entities comprising the regional economy not be diminished.

A broader, conceptual concern is the irreversibility of decisions regarding the mix of crop production and wetlands preservation. Assuming the present social, political, and economic climate encourages crop production at the expense of wetlands preservation, does not imply a similar set of circumstances 25 or 50 years into the future. As long as wetlands can be restored (and evidence suggests prairie potholes can be restored), then that option remains open to future generations. If selected wetlands or conglomerations of wetlands are unique or perform unique services that cannot be restored, opting in favor of preservation until further information becomes available provides a social safety net.

Summary and Conclusions

A cursory introduction to a two-output production possibilities frontier has demonstrated how resource owners make production decisions based on trade-offs in their levels of satisfaction. The issue of wetlands preservation highlights this trade-off in light of private versus public goods. While the landowner who drains wetlands may be acting in his own best interest (as may be the landowner who preserves wetlands), the interests of society are excluded from his decision making. Alternatively, social demands to preserve wetlands do not adequately consider the values and interests of landowners. There are no "bad guys" in this controversy, only conflicting interests in use of the same resource.

Several policy instruments were suggested that could achieve Pareto optimality (make no one worse off, yet make some better off). The successful implementation of these policies depends upon a clear understanding of both landowners' and society's rights and values.

Literature Cited

Apedaile, L.P. and E. Rapp. 1983. "Areas Affected by Excess Water on Better Quality Cultivated Land in East Central Alberta." *Agriculture and Forestry Bulletin* 6(4):27-32.

Baumol, William J. and Wallace E. Oates. 1979. *Economics, Environmental Policy, and the Quality of Life*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Kusler, Jon A. 1983. *Our National Wetland Heritage: A Protection Guidebook*. Environmental Law Institute, Washington, D.C.

Leitch, Jay A. and Daniel E. Kerestes. 1981. Agricultural Land Drainage Costs and Returns in Minnesota. Department of Agricultural Applied Economics Staff Paper P81-15, University of Minnesota, St. Paul.

Office of Technology Assessment. 1984. *Wetlands: Their Use and Regulation*. U.S. Congress, Government Printing Office, Washington, D.C.

Rigaux, L.R. and R.H. Singh. 1977. *Benefit-Cost Evaluation of Improved Levels of Agricultural Drainage in Manitoba*. Volume 3: *Economic Feasibility of Investment*. Research Bulletin No. 77-1, Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg.

Smutko, L. Steven, Jay A. Leitch, Leon E. Danielson, and Rodney K. Strohh. 1984. *Landowner Attitudes Toward Wetland Preservation Policies in the Prairie Pothole Region*. Department of Agricultural Economics Misc. Rpt. No. 78, North Dakota State University, Fargo.

Stromstad, Ronald A. 1983. " A Wetland Program that Would Work." *North Dakota Outdoors* 45(8):10-13.

THE EFFECTS OF LAND USE CHANGES AND ACTIVITIES ON WALLEYE REPRODUCTION SUCCESS IN THE VALLEY RIVER, MANITOBA

Commercial walleye yields from Dauphin Lake have decreased by 95% from the high levels attained in the 1940's and 1950's (Fig. 1). Declines in walleye production appear to be related to poor spawning success in tributaries of Dauphin Lake, and directly or indirectly caused by: 1) stream channelization, 2) land clearing and wetland drainage, and 3) physical obstruction to fish during spawning migrations.

A fisheries study was initiated on the Valley River (Fig. 2) in 1982 to attain a better understanding of the spawning and incubation requirements of walleye, and to determine the factor(s) limiting walleye reproductive success. Also a remote sensing study of aerial and Landsat photography was undertaken to quantify the changes from 1948 to 1980 in the amount of cultivated land, woodland, wetland, and pasture land within the Valley River watershed.

Lands within the Valley River watershed are used primarily for agricultural purposes. However in comparison to the other five major tributaries of Dauphin Lake, the Valley River has undergone the least amount of physical alteration with very little channelization and the lowest sediment input per unit of watershed area.

Field studies were conducted in 1982 and 1983. Valley River discharges during April and May were much higher in 1983 than in 1982 (Fig. 3). The warming rate of water was slightly higher in 1982 than in 1983 (Fig. 3). Drift net catches of larval fishes indicated much higher numbers of walleye, white sucker and quillback drifting in 1983 than in 1982 (Fig. 4). Total drift net catches ranged between 5 and 166 times higher and estimated production was between 30 and 1200 times greater in 1983 than in 1982. Also the number of yellow perch larvae caught in the drift net increased from 0 in 1982 to a total of 1200 in 1983. Adult fish captures indicated that the brood stock size of walleye and suckers increased only slightly from 1982 to 1983.

The land use/land cover study showed that by 1980 there was 63% more land under cultivation than there was in 1948, but 44% less woodland, 20% less pasture and 68% fewer wetlands (Fig. 5). It is believed that land clearing and wetland drainage has resulted in increased peak discharges of the Valley River and a more rapid attenuation of flows after peak discharge during spring run-off (Fig.6). The average spring peak discharge currently in the Valley River is almost double the average discharge recorded between 1913 to 1927.

The loss of woodlands and wetlands has resulted in the rapid flushing of the Valley River because wooded land would retain the snow for a longer period, thus prolonging the snowmelt period and consequently providing lower peak flows and a gradual decline in flows after peak. Also wetlands and swamps would act as water storage reservoirs, buffering the amplitude of extreme flows.

It was evident then that flows in the Valley River had changed from the historic hydrologic regime, and that reproductive success of percids and suckers was greater under higher discharges. In particular it appeared that the minimum discharge during the spawning and incubation period may be an indicator of potential reproductive success.

A duration curve of the minimum discharges which occur each year during the spawning and incubation periods of walleye (i.e. from peak snowmelt discharge up to 50 days after peak) indicated a greater frequency of very low flows now than in comparison to the 1913 to 1927 period (Fig. 7). For example, 50% of the time now flows are less than 3 $m^3 \cdot sec^{-1}$ while in the past, flows less than $3m^3 \cdot sec^{-1}$ occurred in only 10% of the years.

A computer program called PHABSIM (Physical Habitat Simulation) was obtained from the U. S. Fish and Wildlife Service, Cooperative Instream Flow Group of Colorado to determine how discharge may affect the amount of available walleye spawning area. This program required as input several cross-sectional velocity and elevation profiles from a spawning area on the Valley River, as well as the preferred velocities, depths and substrates of spawning walleye. Range and optimum values for velocity, depth and substrate were determined for Valley River walleye by egg collections at various spawning areas. These values were then normalized and plotted, with unity indicating ideal conditions and zero indicating conditions unused by spawning walleye (Fig. 8). The normalized plots are termed habitat suitability curves. The computer program then integrated the stream profiles and habitat suitability curves, and provided a relationship between discharge and the amount of walleye spawning area per km of stream.

Maximum spawning area occurred at a discharge of approximately 10 $m^3 \cdot sec^{-1}$ (Fig. 9). Approximately 11 times more spawning area was available for walleye in 1983 (9000 $m^2 \cdot km^{-1}$) than in 1982 (800 $m^2 \cdot km^{-1}$). This relationship helped to explain the greater reproductive success of both percid and sucker species in 1983 in comparison to 1982.

A duration curve showing the historic changes in the amount of available spawning area was constructed by interpolating from Fig. 9 the amount of spawning area at the minimum flows which occurred each year during the spawning and incubation periods of walleye (Fig. 10). It was evident that between 1972 and 1983 there was less than 3000 $m^2 \cdot km^{-1}$ of spawning area available in 5 out of 10 years, while from 1913 to 1927 less than 3000 $m^2 \cdot km^{-1}$ occurred in only 1 out of 10 years.

Another objective of our study was to determine to what extent sedimentation affects the survival of walleye eggs. Approximately 1000 walleye eggs were stocked on experimental trays (Fig. 11) and their survival and rate of accumulation of sediment (silts and clays) in the Valley River were recorded over a 20 day period. The experiment clearly demonstrated the negative impact of sedimentation of silts and clays on the survival of walleye eggs (Fig. 12). At site E where sedimentation rates of silts and clays were high, egg survival was low.

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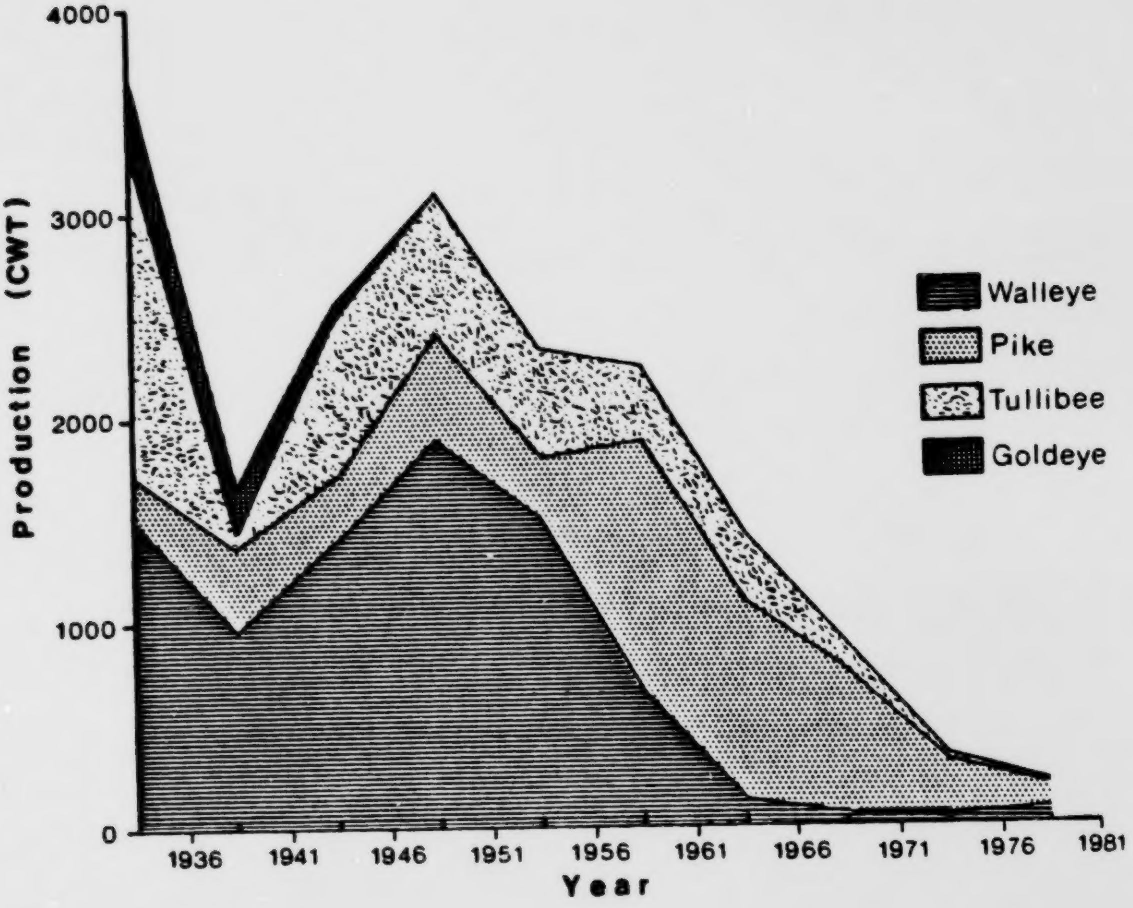

Fig. 1. Dauphin Lake commercial production shown as five-year averages from 1931 to 1981.

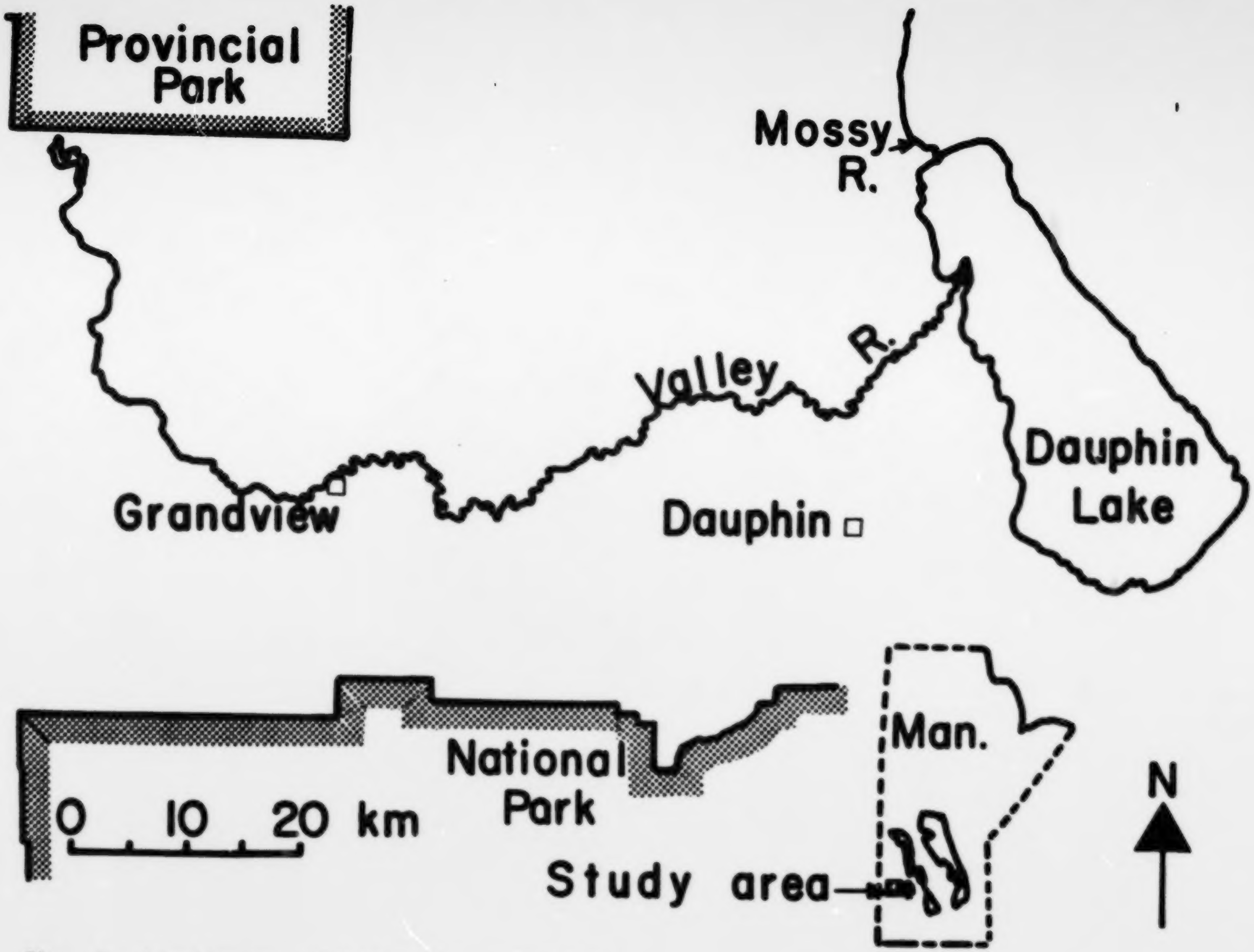
Provincial Park
Mossy R.
Valley R.
Dauphin Lake
Grandview
Dauphin
National Park
0 10 20 km
Man.
Study area
N

Fig. 2. Location map of Valley River watershed.

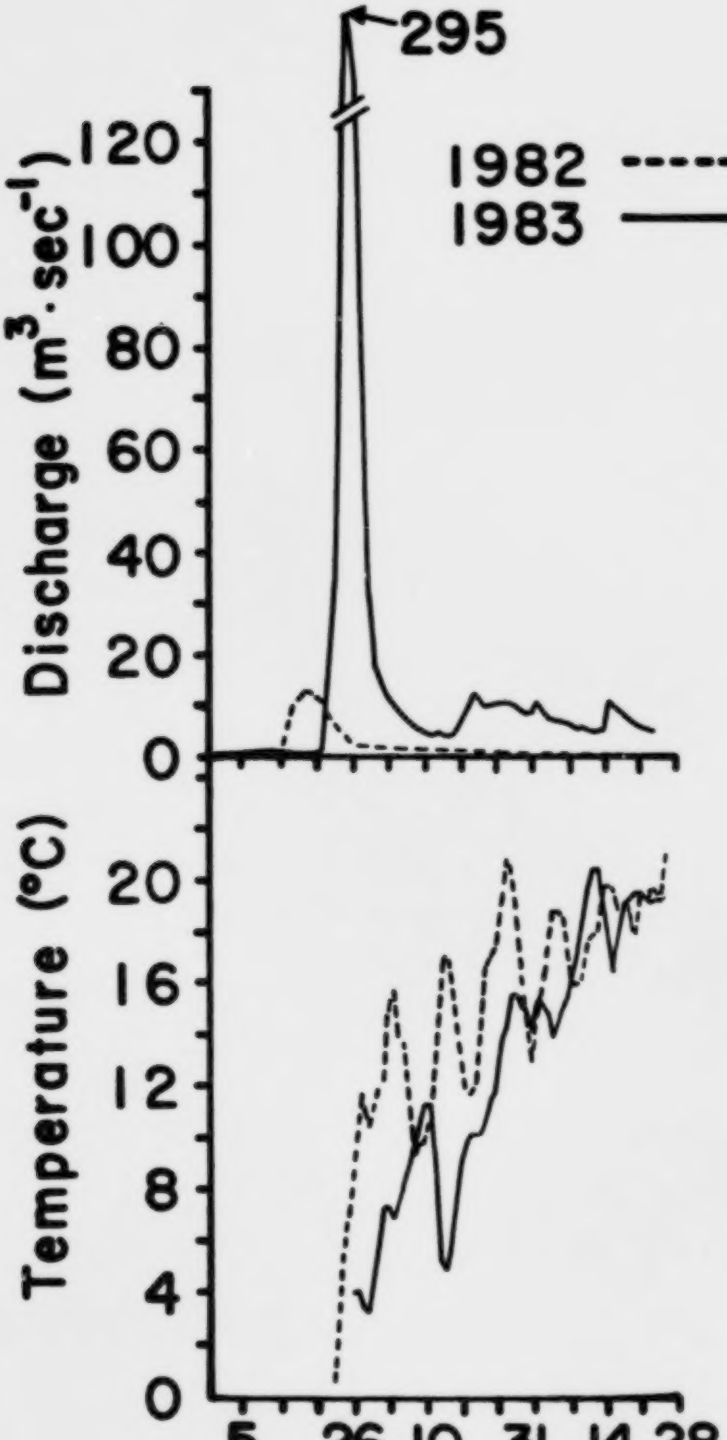

Fig. 3. Mean daily discharge and maximum daily water temperature of the Valley River.

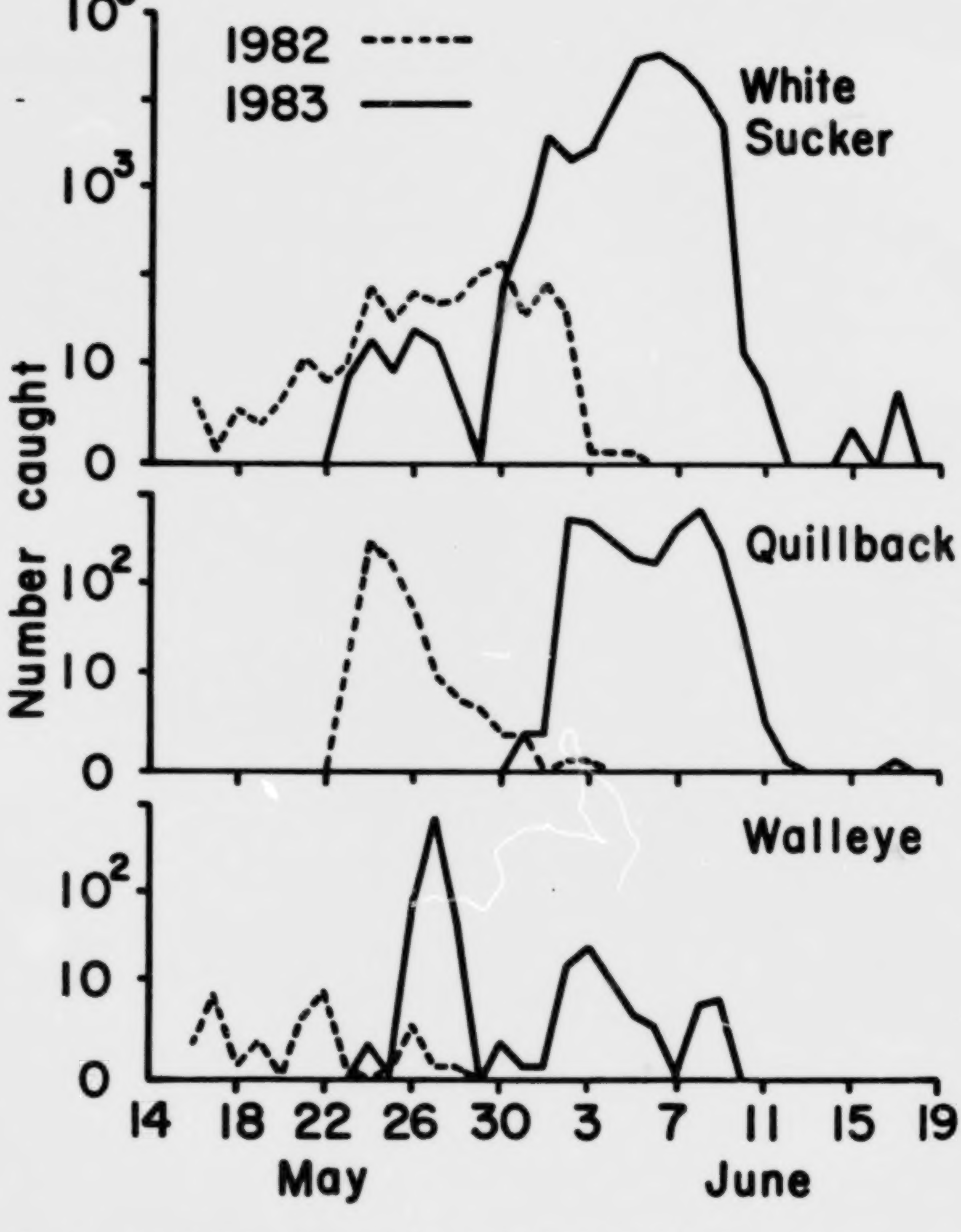

Fig. 4. Larval fish catches from a single drift net location in the Valley River.

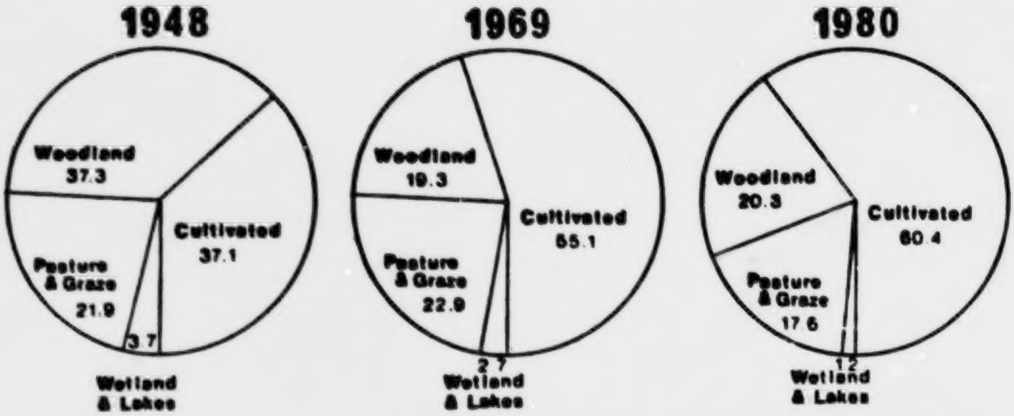

Fig. 5. Land use changes in the Valley River watershed (excluding park areas), 1948 - 1980.

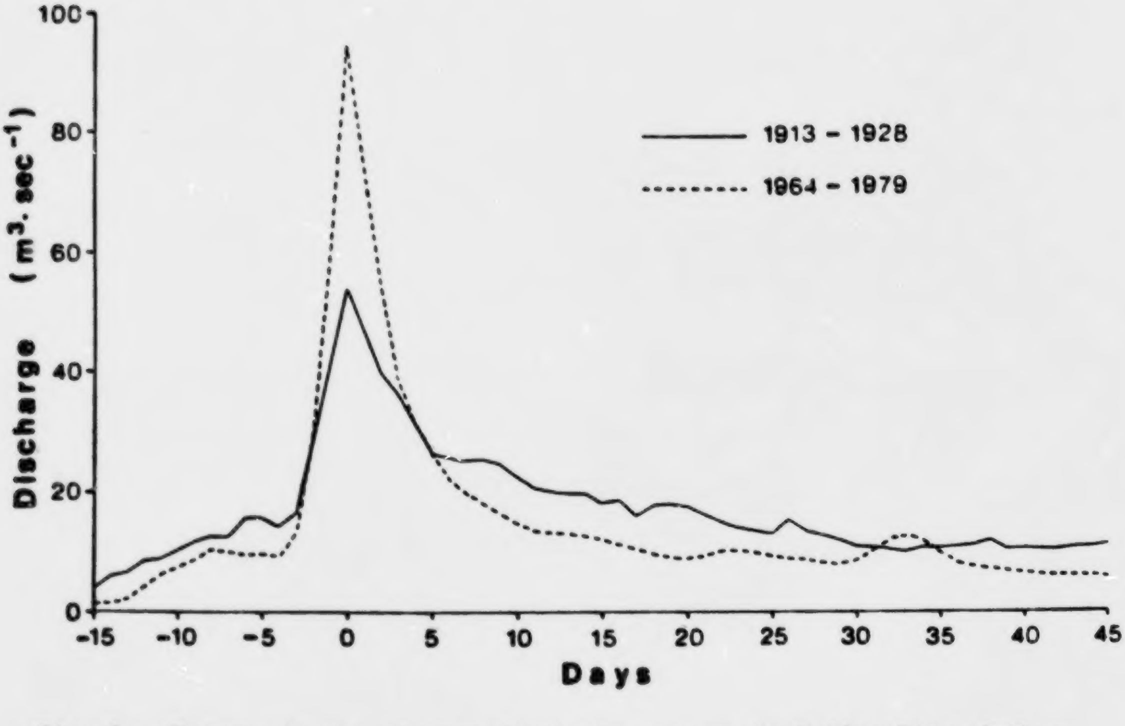

Fig. 6. Changes in the average discharge pattern in Valley River before and after spring peak (day 0), 1913 - 1928 and 1964 - 1979.

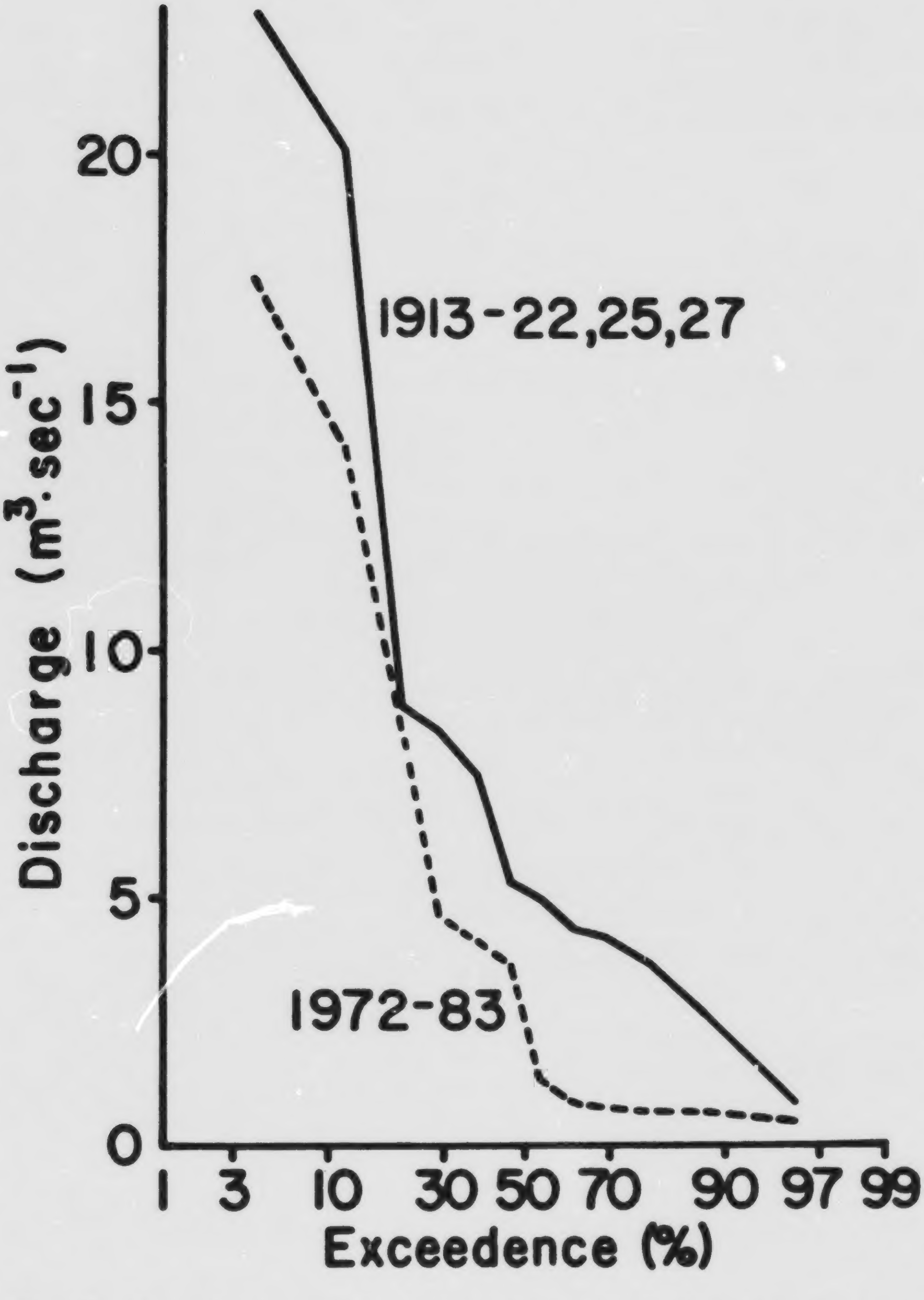

Fig. 7. Duration curve of historical and present discharges in the Valley River.

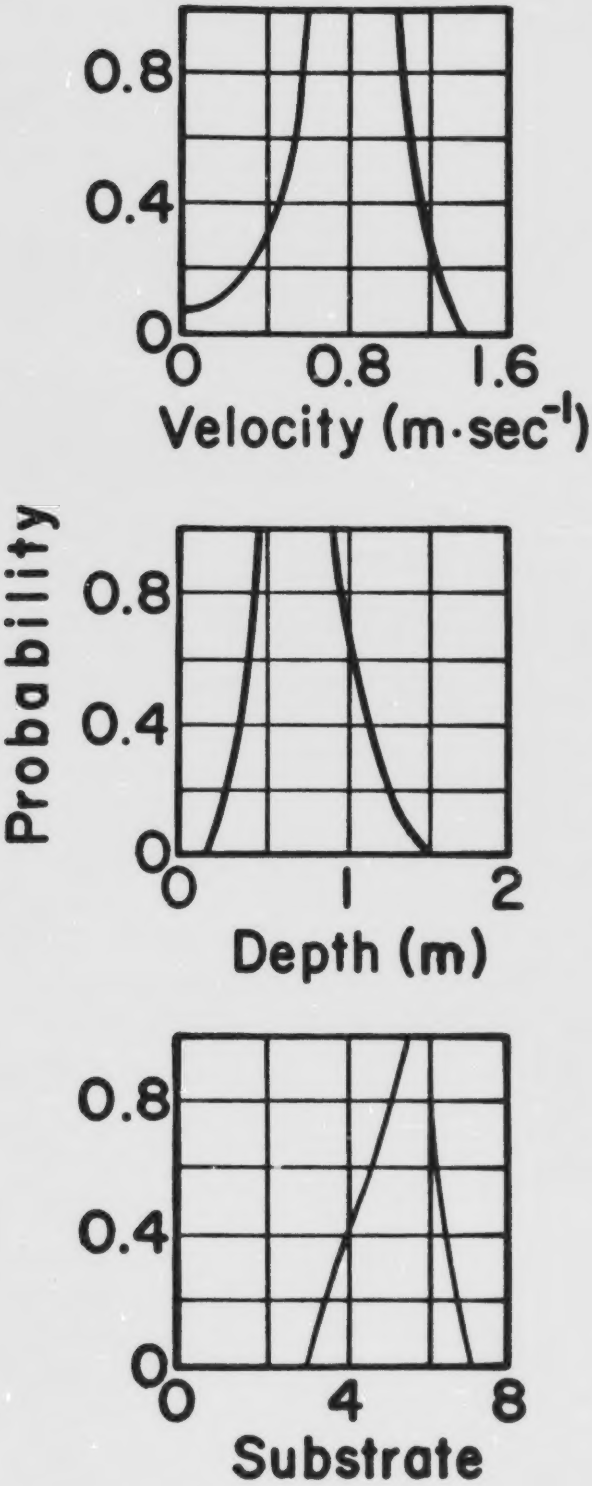

Fig. 8. Habitat suitability curves for walleye.

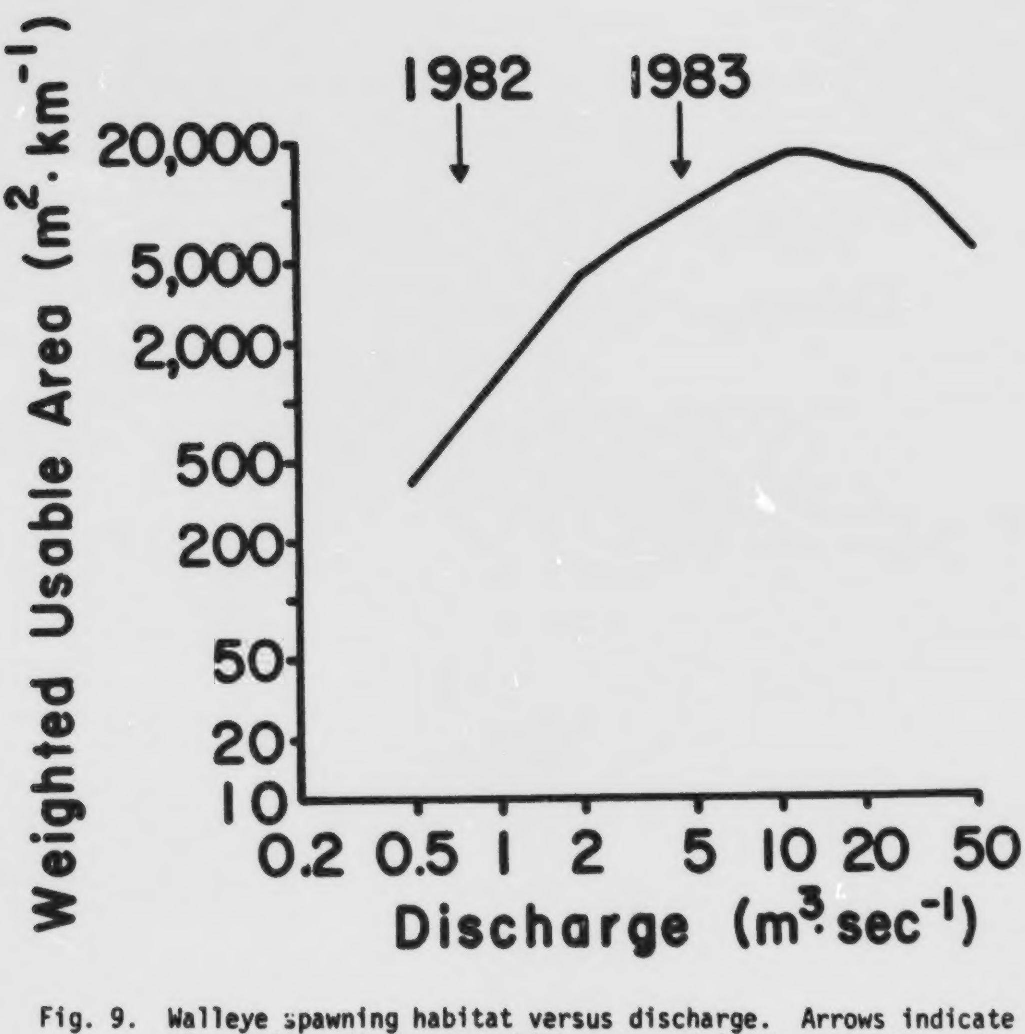

Fig. 9. Walleye spawning habitat versus discharge. Arrows indicate the minimum discharges which occurred in the spawning and incubation periods in 1982 and 1983.

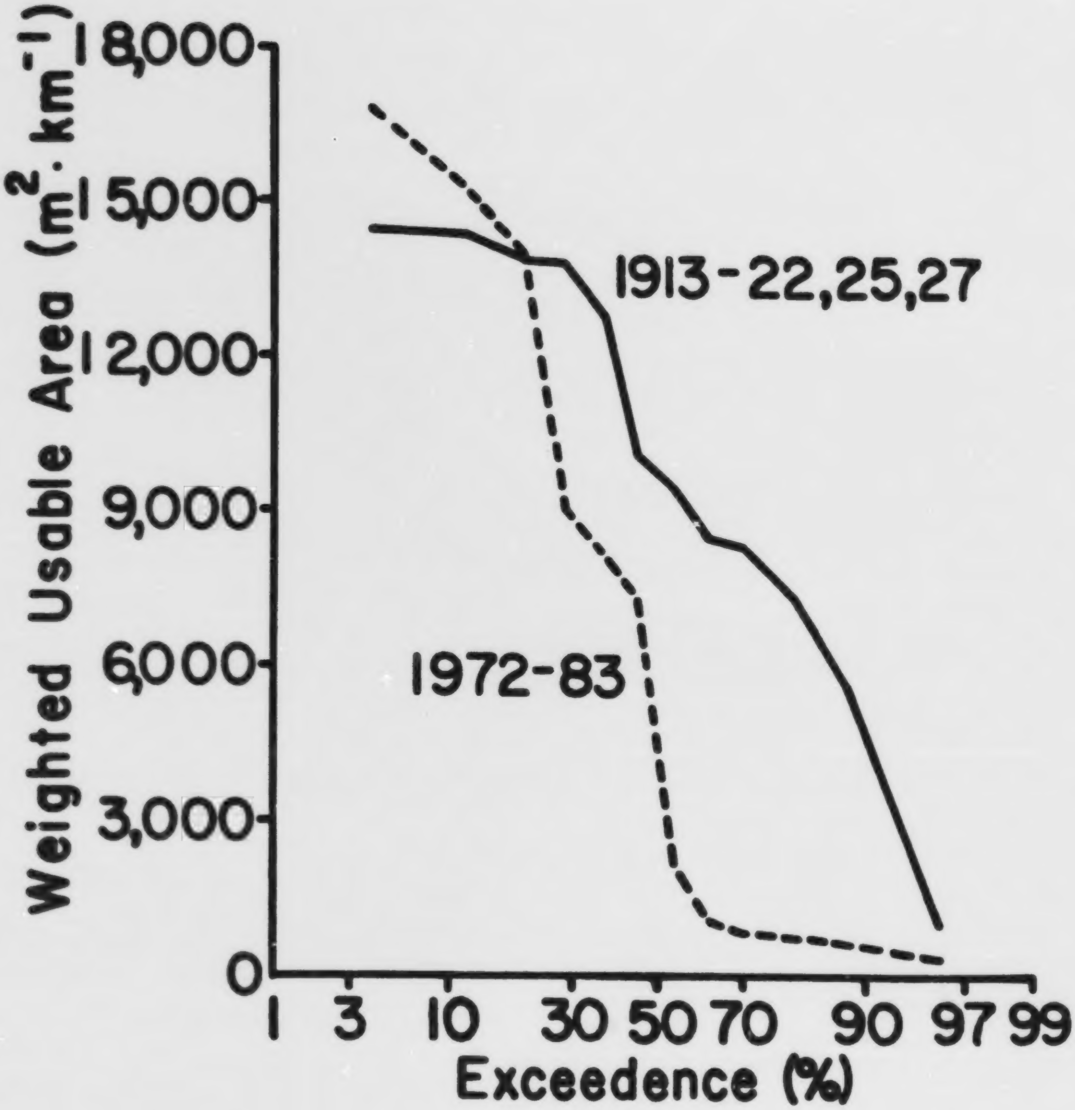

Fig. 10. Duration curve of historical and present spawning habitat area for walleye in the Valley River.

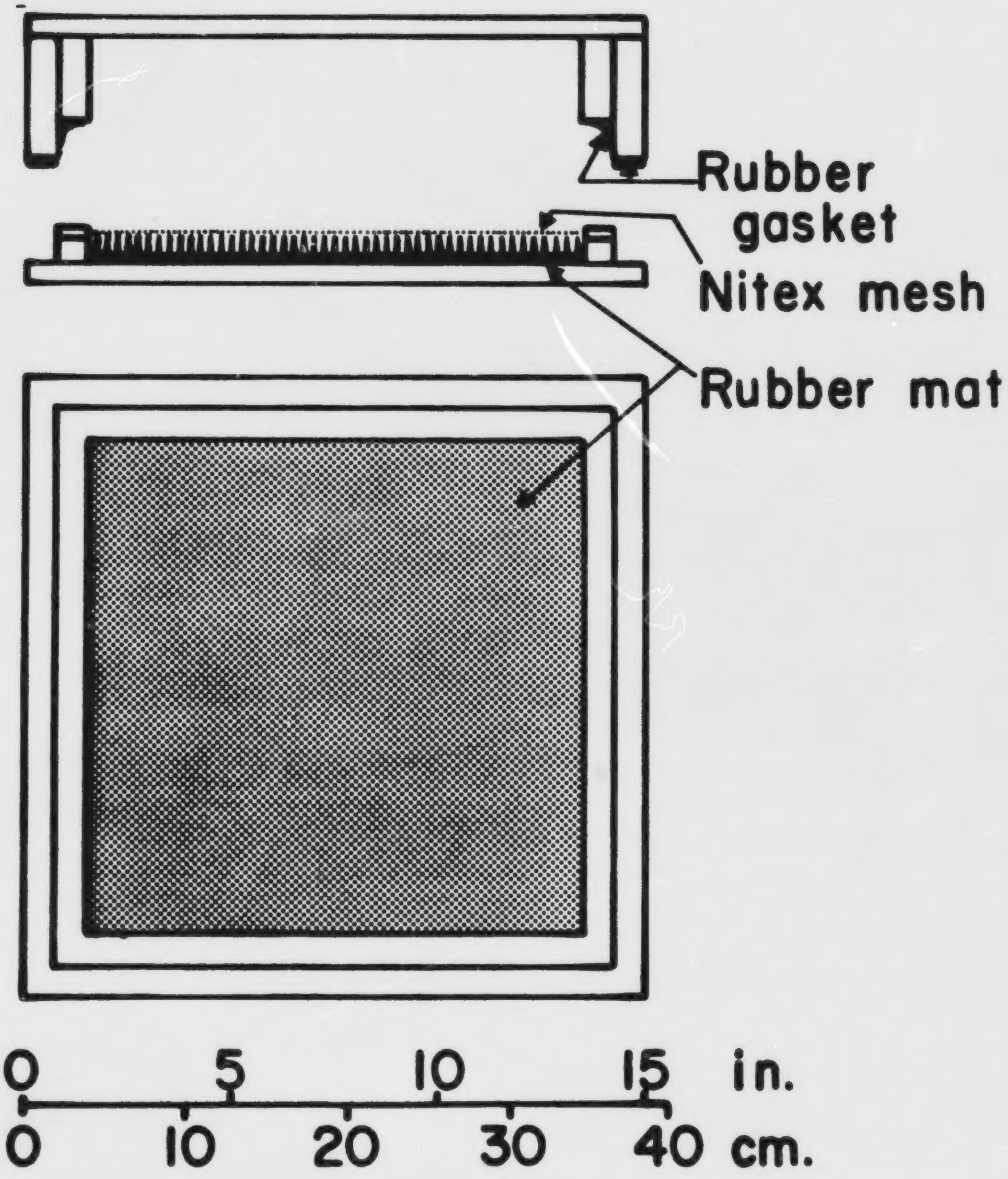
Rubber gasket
Nitex mesh
Rubber mat
0 5 10 15 in.
0 10 20 30 40 cm.

Fig. 11. Specifications of tray constructed for the egg survival and sediment deposition experiment.

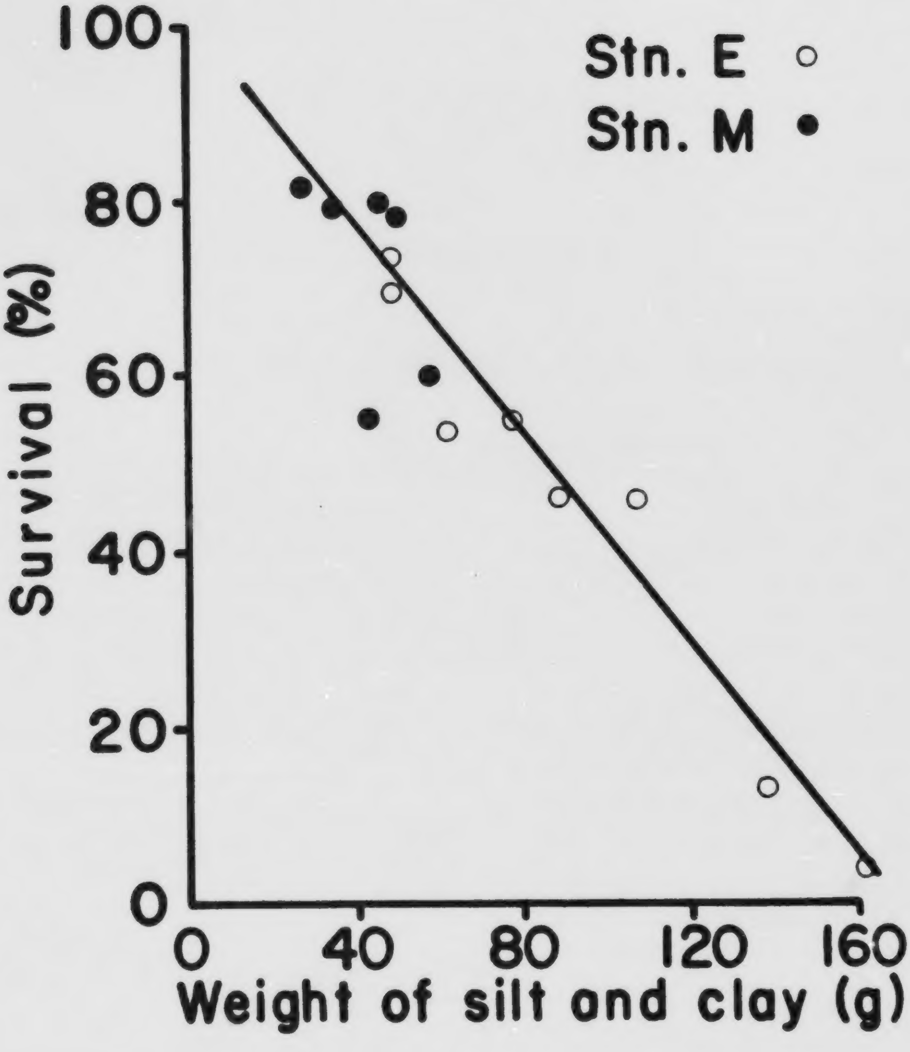

Fig. 12. Relationship between silt and clay deposition and walleye egg survival, Valley River, 1983.

Make Your Wetland Work for You

by Joseph P. Rossillon

President

Freshwater Foundation

Historically, on the North American continent we have been guilty of discrimination when it comes to wetlands. From a management standpoint we have always viewed wetlands as land when in actuality they are water. Wetlands are not farms, they are small shallow lakes and as such play an intergal role in the watershed system.

One should never forget that water is an intimately interrelated system. Man intervenes into that system for good or bad.

Wetlands have a job to do, they are involved in flood control, they are involved in water storage and the cleansing process. When we eliminate wetlands, and alter the interrelated natural system of water and we reap the impacts of that intervention.

Contrary to public opinion, the primary role of water in nature is not to support man. Its first function is as Mother Nature's sewer system because everything in the Universe ends up in water to be broken down or cleansed through biological action or biodegradation.

We should not view water as pristine and clear but in the same way that we view a septic tank. Three things will make a septic system malfunction a) overload the system; b) kill the bacteria that are responsible for the cleansing process; or, c) introduce something that the bacteria don't recognize; that same process and the same rules hold true with all surface and groundwater.

If water is Mother Nature's sewer system, then wetlands are the septic tanks. Wetlands are marvelous places to hold nutrient compounds while the natural biological action occurs to break down the materials and allow the plant life to absorb the nutrients. As water leaves the wetlands it has been recycled and less contaminated.

When wetlands are drained two things occur. One, the water rushes in great volumes through the river and streams in a contaminated state causing a build up of contamination as the water heads to the ocean. This build up of volume also enhances periodic flooding.

The second thing that occurs is more direct recharge of groundwater and a resulting potential increase of contamination of that water supply.

In Western Minnesota along what is called the Bonanza Valley, a great sand plain, that is highly dependent upon irrigation and heavy fertilizer and chemical applications to assure high corn production, nitrate levels at 20 parts per million are building as deep as ninety feet in farm wells. Organic compounds (herbidices) have been discovered in up to 50 percent of the wells tested at significant levels. Although this water supply is still acceptable for irrigation, a supplemental supply will have to be introduced to provide for the farm families and the livestock.

In Clayton County in northeastern Iowa, not only has the nitrate and organic levels increased in farm wells but during the month of June and early July the chemicals used as herbicides have been found in the wells to such a concentration that researchers could actually identify three brand names.

When contaminates are introduced into the groundwater not only is a water supply contaminated but a further complication occurs. In nature there are two basic categories of bacteria, aerobic and anaerobic. Aerobic bacteria live in an oxygen charged environment. Anaerobic bacteria live in an oxygen free environment like groundwater or the bottom of lakes. Anaerobic bacteria are only about one-third as efficient as aerobic bacteria so when contaminates are leached into groundwater it is three times more difficult to clean up that material by biological action than would be in a surface water supply like a wetland.

In the United States over the years we have made three major errors in relationship to wetlands and groundwater supplies. The first could be called "the 208 error".

In the early seventies the 208 Water Quality Act was passed which said that "by 1985 all surface waters in the United States should be fishable and swimmable." Of course, it isn't going to happen but great strides have been made in cleaning up the point source pollutants in surface water. The error in the law was not including groundwater. The law established that pollutants could not be dumped in surface water. It doesn't say "don't create pollutants" so the only sensible and remaining place to dump pollutants was to bury them in the ground. As a result we are witnessing chronic broad scale contamination of groundwater supplies in the United States. As was stated earlier, groundwater is much more difficult to clean than surface water. In addition, many surface water filters have been lost through drainage and now it is estimated by the U.S. EPA, that 73 percent of all the rural wells in the United States are contaminated.

The second error could be called the "U.S. Corp of Engineers error". In an attempt to increase agriculture production and as a result of taxing the farm units to the degree that wetland drainage became a necessity or normal procedure we increased the occurrence and intensity of flooding across the United States. As a corrective measure we assigned the corp of engineers to take corrective action in the form of building major flood control storage basins. An example of this erroneous logic almost, but didn't occur on the Minnesota River.

Thousands of acres of marginal farming land was created through wetland drainage in the southwestern part of the state. To alleviate the potential of flooding in the Twin Cities and St. Louis, Missouri the Corp of Engineers recommended building a massive flood control dam across the Missouri River near New Ulm, Minnesota, with the result that the impoundment would have flooded millions of acres of the most productive agricultural land in the state. The ultimate trade-off would have been thousands of acres of marginal land for millions of acres of the most productive land - a poor bargain at best.

The third long range error was the effort "to make deserts bloom." We as a civilized society oft times suffer from the assumption that "man is dominate over nature" and can do anything he wants, anyplace, anytime. In fact, nature is rather understanding and patient but in the long run always does what is natural. When a volcano is going to erupt, it erupts. When a massive rain storm is going to occur, it occurs. When a drought is eminent it will happen. And El Nino is El Nino. But our society often times labor under the assumption that we have "the right" to live where we want, in any manner we want, and to making a living in the manner we want regardless of the natural surroundings. In order to do this we attempt to redesign nature. In fact, man cannot create geology or recreate the earth.

Through the discovery of some massive underground aquifers in the United States we have enjoyed the good fortune for a number years of watching the desert bloom. One of greatest of all aquifers, the Ogalalla, has provided for corn production through five of the central states in the United States in areas where originally only tumble weed existed. Now we are told that the Ogalalla will be pumped dry by the year 2010 - 2020. Now, what we are attempting to do, politically, is replace that water with massive relocations of surface water. In other words, we are attempting to create and sustain a dislocated artificial environment. It will never work.

The economy of the United States is based upon free water. Never in our history has any one been asked to pay for water at the source. But as the need increases for water in isolated areas the question of selling water emerges. South Dakota was the first state to sell water at the source for the insignificant sum of two-tenths of a cent per gallon. But, if that price were factored into everything we do the results would be astronomical. Three examples: such a price would add ten dollars to a bushel of corn; eight dollars to a pound of beef; and three dollars to a hamburger, fries and cola.

From these observations it is clear that we, as a society, cannot do everything that we want to do in everywhere, at anytime but must adapt to our natural surroundings just as everything else in nature adapts. Mother Nature is far more receptive to "fine tuning" and subtle adjustment than she is to "use a bigger hammer".

Next comes the question of making wetlands pay for themselves. It is unrealistic for any state or nation to tax wetlands as they would land and expect the owners to let those acres lay idol and not reap some income from them. The land owner is left with two choices: Drain the wetlands and put them into agricultural production; make the wetlands pay for themselves. I opt for the second choice and I recommend three alternatives to draining and farming; 1) wetlands as storage tanks; 2) wetlands as water filters; and 3) tax and fee incentives for wetlands.

1. Storage Tanks

A gentleman from Winnepeg suggested that an alternative to flooding would be "a dumping tax" in which the property owner must pay a tax on all water that runs off that property. The tax would be regulated depending upon the time rate of water ran off - whether it was in a high flow period or a low flow period. If the water was held to a time when there was less potential for flooding, the taxes would be significantly reduced. With such a proposal a wetlands would be very valuable as a storage tank and would help pay for itself in reduced taxes.

A second use as a storage tank is in the irrigation process. Water held to control flooding can be used for irrigation and consumption.

Community and watershed control is greatly benefited from wetlands. A community being protected from flooding by wetlands should be required to pay the support of that wetland.

Finally, wetlands are an intricate part of the recharge system of groundwater and if groundwater is being used for irrigation a tax could be charged against the pumpers to help support the wetlands on the surface.

2. Wetland as water filters

The second real value of wetlands is in relation to water quality. The 208 Water Quality Act in the United States dealt with both "point source" and "non-point source" pollution. Point source is the pipe coming out of the building and going directly into the river - easy to isolate and control. The U.S. hasn't done very well with non-point source of pollution because it is more attitude than anything else.

Non-point source pollution is the way we live, and work and that effect upon the total watershed. There is no single source. Two ways to reduce non-point source pollution is 1) through working and living habits and 2) through surface water cleansing processes like sewage treatment plants and wetlands.

Remember that water is Mother Nature's sewer system and everything that goes into water eventually ends up in the drinking supply. One nice thing about non-point source pollution is that the polluter hurts himself in the process. Whatever you put on the ground or in the ground ultimately will end up in the supply if it isn't treated on the surface. Wetlands can be a very valuable linkage in this process.

Wetlands also are valuable in wastewater treatment. In Saskatchewan, an excellent demonstration plot showed how cattails took nutrient from a wastewater treatment system and the discharge supply was almost clean enough to drink. In addition, the cattails and a water plant make excellent secondary energy sources and should be considered as such.

3. Tax and fee incentives

The third source of income from a wetland can be from taxes and fees. With each new generation on the North American Continent we've come closer to the time where current held rights, like hunting, are not inherent rights but privileges that must be earned and paid for. Wetlands are an excellent source of water foul hunting and trapping and bird-watching and there is no reason why the fees charged for these privileges shouldn't help supplement the tax base and maintenance.

In Minnesota there is a tax writeoff called "the Chickadee Checkoff" which enables people to contribute funds to non-game species. This money is raised and used to provide habitat for non-game species. Funds like these could supplement wetlands, because not only are they marvelous places for water foul hunting they are also marvelous places for non-game birds and for bird watching. We think nothing of paying to go to the zoo to see wild animals. A fee to go see animals at a wetlands area is no more unrealistic.

Finally, if we expect the agriculture community to maintain wetlands some type of tax incentive must be provided so that there is a reason to leave it in water and not put it in crop production. If wetlands are to be taxed like farm land, we can only assume that they will be treated as farming land and drained. We should expect nothing else.

In the final analysis I am not terribly concerned about wildlife and nature. Not that I don't enjoy them and think their most important, but they have a way of taking care of themselves and surviving nearly everything that we do to them. My principle concern is for people who are often too naive to take care of ourselves. Birds don't pay taxes, wildlife don't vote and frankly, I don't think they care where they live as long as the habitat is adequate.

My principle concern with wetlands is that Man understand how intimately interrelated they are in the natural system and how vital they are in maintaining a natural system of water that can support Man. If we take care of our water supply, it will take care of us and we will take care of everything else. If our water supply goes bad on us we will disappear as a civilization and by the way, there is adequate historical proof to confirm that point.

Finally, there is no question in my mind that the agricultural community must get some kind of tax break on wetlands. If wetlands are to be taxed like farm land, we can only assume that they will be treated as farming land and drained and in my mind that's only right.

SESSION V

Conference Summary and Recommendations

Session Chairman: G. H. MacKay

INTRODUCTION

by G. H. (Hugh) MacKay

Good morning and welcome to the fifth and final session of the Third Annual Western Provincial Conference on the Rationalization of Water and Soil Research and Management. For the last two days we have heard 28 papers on agricultural land drainage from the aspects of Soil-Water-Plant Relationships, the Engineering and Economics of Drainage and finally, the Impacts of Drainage. Now it is your turn -- the name of the game this morning is participation.

The Conference program notes: "in 1981, the premiers of the four Western Provinces held discussions on the rationalization of information, activities and applied research related to agricultural soil and water management. The Premiers decided that an annual soil and water management seminar be held to promote a full exchange of information and ideas between professionals from each province." The objective of this morning's session is to try to synthesize the papers and discussion of the previous two days so that we will be able to make a useful report to the western premiers.

In order to assist in achieving this goal, we have scheduled the activities for this session as follows:

First, we will hear three one-half hour summaries, one summary for each of the three working sessions. The summaries will not be a simple listing of the papers, but rather an attempt by each summarizer to catch the essence of the particular session. You will recall that during the past two days you have been asked to consider four questions:

1. "Do we know the effect, quantitatively, of excessive soil moisture on various crops?"
2. "Do we know enough of the physical parameters of soil moisture movement to design effective and efficient works to reduce excessive soil moisture?"
3. "What is required to enhance our ability to quantify the effects on the environment, in economic terms, of reducing excessive soil moisture by land drainage?"
4. "How can agricultural land drainage be efficiently and effectively integrated with multiple use management of soil and water?"

The summaries will relate as much as possible to those questions.

At 10:00, we will break for a working coffee break. We would ask that each of you identify yourselves as representing one of the following groups:

1. Farmers
2. Agricultural organizations such as conservation districts
3. Municipal Councils
4. Provincial agencies and Universities
5. Federal agencies.

During the 45 minute coffee break, we would ask that those in the farmers group gather at the front left of the room; the agricultural organizations centre left; municipalities rear left; provincial agencies and universities front right and federal agencies rear right.

We would ask each group to consider the four questions, the three summaries and try to reach consensus on one or two resolutions or conclusions to be presented to the full session beginning at 10:45. Each group's resolutions will be discussed by the conference and if consensus is obtained will be recorded as a recommendation from the conference to the western premiers.

In order to facilitate group discussion and to present the group's resoltuions, the following people have offered their services:

1. for the Farmers group - Joe Omichinski from Portage la Prairie, Manitoba;
2. for the Agricultural organizations - Bill Poole from the Turtle Mountain Conservation District;
3. for the Municipal Councils - Dave Harms, past president of the Union of Manitoba Municipalities;
4. for the Provincial agencies and Universities - Bill Newton, Engineering and Construction Branch, Manitoba Department of Natural Resources;
5. and for the Federal agencies - Kent Brace, Canadian Wildlife Service.

SUMMARY OF SESSIONS ON SOIL-WATER-PLANT RELATIONSHIPS

by John C. Hermans

Water is one of the key factors affecting crop production. Unfortunately, moisture distribution varies considerably from east to west across our provinces and from north to south within the province. Even if the total amount of moisture may be adequate, the distribution during the growing season may not. This year, for example, while southern Alberta was experiencing its' worst drought in 65 years, some farming areas in northern Alberta received as much as 22 inches of precipitation during the month of June.

One of our speakers this week speculated that if current climate change trends continue, average temperatures will become even warmer. If that is true, moisture shortages may become even more critical in some areas. Therefore, instead of concentrating on draining away all of this precious resource, more emphasis should be placed on managing it. Perhaps a more appropriate title for the conference might have been "On-Farm Water Management".

The speakers outlined many ways that excess moisture affects crop production. For example, wet soils may have low trafficability and thereby influence many farm operations including seeding, spraying, tilling and harvesting. Runoff of excess moisture either during spring snowmelt or intense summer rains results in loss of productivity through erosion of valuable topsoil. Much of the dryland salinity that affects crop production on millions of acres of prairie soils is also the result of excess moisture entering groundwater flow systems through recharge areas. Salts are dissolved along the flow system and concentrated in discharge areas when the water evaporates.

Fortunately, most of these problems, it seems, can be controlled by "managing" the water properly. Management options begin with on-farm practices such as maintaining stubble, instead of excessively tilling the land. This traps the snow allowing the moisture to infiltrate into the soil when it melts instead of running off quickly. With the aid of hydrogeological investigations, lands defined as recharge areas for saline seeps may be seeded to high moisture use crops such as alfalfa that will "intercept" and use up excess moisture. These "natural" controls have the advantage that they control the problem at the source, are less expensive and usually provide more permanent solutions.

Situations often arise however, where these controls are not feasible and other solutions must be considered. If an outlet is available, tile drainage is one option that should be considered both for consolidating surface water bodies or for lowering watertables to control waterlogged soils and saline discharges. Our speakers emphasized that proper designs to determine the correct depth and spacing of tiles and proper installation are critical if the systems are to work effectively. Water quality from the outlet may also be a concern, particularly when draining saline soils or when considering vertical drains into other aquifers.

There is a misconception that if land can be drained, it can be farmed. Soil quality however, is also an important factor that should be considered as some soil properties may result in physical or fertility problems and may not in fact be economical to improve. For example, saline/sodic soils, once drainage and leached of soluble salts, may become impermeable. Peatlands may be very acid and require large inputs or lime before they are farmable.

In summary, there are many soil-water-plant interrelationships that we must consider before draining agricultural lands. The papers presented in this session outline some of the new technology that is available and also addresses many of the problems and concerns related to it. If we are to be successful in implementing some of these water management concepts, we need to develop technology transfer "packages" that will be both practical and economical at the farm level. An important part of this package will be an awareness campaign to demonstrate to farmers the benefits for themselves and their neighbours of using good on-farm water management practices.

SUMMARY OF SESSIONS ON ENGINEERING AND ECONOMICS

by Derek Doyle

This summary briefly answers from the author's perspective, the four (4) questions posed by the conference organizing committee, then goes on to briefly indicate the main points drawn from the excellent papers presented in the session.

QUESTION 1. "Do we know the effect, quantitatively, of excessive soil moisture on various crops?"

Answer: It appears that indeed we do know the effect, within the bounds of reasonable uncertainty. Indeed if we are to procrastinate in our decision making on the grounds that we do not "know it all", then we will fail and fail miserably to make the necessary decisions today and plan a course of action for tomorrow.

QUESTION 2. "Do we know enough of the physical parametrers of soil moisture movement to design effective and efficient works to reduce excessive soil moisture?"

Answer: Again, we do on the basis of reasonable uncertainty. There are some notable exceptions however, namely; in wetsands and peatlands.

QUESTION 3. "What is required to enhance our ability to quantify the effects on the environment, in economic terms, of reducing excessive soil moisture by land drainage?"

Answer: We should build "decision baskets" around which the various parties at interest can agree to cooperate. Just as one constructs an attractive fruit basket by combining apples, oranges, bananas and grapes, one should contrive land drainage packages that respond to the needs of farmers, local authorities, cooperating associations, municipal, provincial and federal governments.

Acceptable attractive "baskets" cannot be forged by the "apple" advocate excluding all other fruits. In essence, what is required is acceptable attractive deals for all agencies. In order for this to occur, each party at interest must have a "ZEAL for a DEAL". Decision makers should be determined to construct first generation action plans in the full knowledge, that as time goes by, second generation and third generation plans and programs can be devised. We must not wait for the certainty of third generation plans in order to make a deal today and act as determined decision makers.

QUESTION 4. "How can agricultural drainage be efficiently and effectively integreated with multiple use management of soil and water?"

Answer: As a first step, we must clearly differentiate between the removal of rainfall from crops, versus the impacts of flooding, whether from spring thaw or rapid conveyance of rainfall in the downstream channel. Local officials and landowners frequently assume that an infrastructure to accomplish excess summer precipitation removal is also an infrastructure for flood control. This misconception must be removed by constant, clear communication by all those involved in drainage development.

Secondly, we should recognize that there are certain historical realities of drainage development. Let me suggest that jurisdictions pass through different phases of drainage development: 1) Enabling Phase, 2) Technological Phase, 3) Regulatory Phase and 4) Organizational Phase. We have heard from a number of speakers the realities of phase 1 where legislation enabled groups to borrow money for the purpose of carrying out drainage works. We are familiar with the technological advances in modelling and mathematics that have drawn many agencies into and through a technological phase of drainage development. We have heard recent examples of the regulatory phase where agencies respond to complaints or by a process of permitting deal with drainage development. Finally, we have heard from cooperating associations and conservation districts about the complexity of drainage planning and on the need for complete cooperation throughout the watershed by landowners and various levels of government. This indeed seems to be the phase that many are now entering.

Thirdly, we need to be integrators and interdisciplinarians. As our technological skills become fine tuned, we need now to bring the integrators into the decision process and afford them a stronger voice. It is these people who will forge the organizational solutions around the technical and regulatory realities of the world.

Fourthly, we must reward desired behaviour. This will require that the incentives be innovative, such as placing a tax or levy on water discharges that are released at an inappropriate time or creating financial incentives for people to retain water until it is appropriate from a watershed management standpoint to release it. Such levies could be based upon volume, timing and possibly quality of effluent. Overall, if we are not rewarding the desired behaviour then we will always be confronted with undesirable behaviour because the incentive structure is luring decision makers in the wrong direction.

Finally, we must "settle the land". In essence, I view the past hundred years as a period of "invading the land". We have changed the face of the country to meet our needs. In doing so, we have learned from many successes and have seen many failures. We must again examine our use of the land with a view to "settling" into a pattern of land use that will endure forever.

The following paragraphs summarize the eight (8) papers presented in this section of the conference.

Legislation and policy in Saskatchewan were reviewed by Mr. Gatin. The paper pointed out that no regulatory legislation existed until 1981. Prior to that the main focus had been on enabling legislation. Currently the new Saskatchewan Water Corporation has been given the clout to prosecute in this area however, the corporation must rely on a complaint process since there is no provision for an enforcement element in the corporation. Guidelines and terms and conditions, related to approvals, noted that mechanisms existed to place controls on flow levels, to freeze project development or to place proposals in abeyance until appropriate mitigative measures have been devised.

In the history of land drainage in North Dakota, Mr. Sprynczynatyk reviewed how the initial emphasis on drainage was providing an enabling framework. This was supported by federal financial incentives and frequently lead to indiscriminate drainage. In the 1950's the Soil Conservation Service, a federal agency, commenced projects taking into account the watershed as a management unit. State and local participation at this time was minimal. In 1957, a drainage permit was required however, no consequences resulted from failing to obtain such a permit. At the same time the Fish and Wildlife Coordination Act was enacted. In 1969, the National Environment Protection Act came into being. In 1975, authoring was handed to local water management entities with the added capability of criminal prosecution. In 1977, a presidential order directed agencies to minimize wetland destruction. In 1981, the state required consideration of all items of public interest in drainage projects. Thus, a comprehensive view involving all organizations is of recent vintage in North Dakota. The paper also outlined criteria and specific considerations that are addressed in the current approval process.

Mr. Poole provided a field viewpoint on conservation districts. The paper outlined the purpose, formation, role and cost-sharing arrangements currently in place in Manitoba. In addition, examples of water management programs were enumerated. The use of runway stabilization and gradient control structures to reduce erosion were demonstrated.

Shale traps and headwater control structures to reduce sedimentation have been successfully applied in several conservation districts. The use of double culverts as a solution to icing problems and the development of temporary storage ponds to deal with storm water control were outlined. A project on pothole consolodation to achieve water retention was reviewed. In summary, conservation districts provide access to incentives and resources, both public and private to affect comprehensive management of our soil, water and other resources. The author pointed out the advances of the past 20 years have been in the pump rather than in the well. The necessity to deal with problems on a watershed basis by a locally governing body was emphasized.

A program to assist farmers in undertaking their own work of planning on-farm drainage was reviewed by Mr. MacAlpine. Conveying rudimentary engineering principles through on-farm problem solving and extension work can be an effective tool for improved on-farm drainage. Field surface drainage standards were reviewed. Benefits of a student surveying service in helping neighbours to resolve drainage disputes were noted.

In reviewing the economics of drainage in Alberta, Mr. Desjardin treated the conference to a very detailed analysis of modelled drainage situations. It was noted that while the benefits and some of the costs accrue to the farms, many external costs are borne by society. The average cost of surface drainage was noted at $121 per acre, while that for subsurface drainage averaged $525 per acre. The viability of subsurface drainage for irrigated and dry land farming, as well as for saline and non-saline conditions were reviewed.

Mr. Gray reported on work carried out in Manitoba on the modification of artesian aquifers to enhance agricultural drainage. The problem associated with icing as a result of blowouts, flowing wells and springs, into drainage systems were noted. The strategy reported by Mr. Gray was that of modifying aquifer water levels through the construction of relief wells. He cited an example, where a three metre drawdown was achieved by providing relief wells. Aquifer modification is an important tool in responding to icing problems in agricultural drainage from flowing wells.

Drainage design for fish passage were reviewed by Mr. Katopodis. The author noted that hydraulic structures interfere with fish migration. Designing in fish passage to a project is far cheaper than subsequently being required to carry out remedial works. This means that engineering and biological professionals must understand each others problems and be involved early in the process of project design. Costs for fishways at dams, locks, fishlifts were noted. In summary much remains to be learned about accommodating fish passage through culverts. There is however, a wide array of practical design advice available to accommodate fish passage.

Finally, Mr. Lindner provided an insight into the design and construction of an extensive development project. The Namepi-Kennedy Drainage Project was in response to drainage and flooding problems. The project was not justified purely on economic grounds since the benefit-cost ratio was in order of 0.33. The benefits of phasing the work over a period of time, using local contractors and hiring local people, brought many additional benefits to the area that otherwise would not have been realized.

SUMMARY OF SESSIONS ON DRAINAGE IMPACTS

by R. W. (Bob) Newbury

Comments

The Chairman has asked me to address the last question posed by Mr. Austford at the beginning of this conference, which was:

> "HOW CAN AGRICULTURAL DRAINAGE BE EFFECTIVELY AND EFFICIENTLY INTEGRATED WITH MULTIPLE-USE MANAGEMENT OF SOIL AND WATER"

Initially, it is important to realize that the drainage will be integrated in the pattern of western Caandian rivers whether water managers and governments will it or not. The problem is, how can we limit or accommodate this integration so as not to eliminate other uses of the aquatic resource.

Although the papers presented in Session IV dealt primarily with drainage impacts, most speakers had positive suggestions about how drainage practices and management could be altered to be more compatible with other aquatic uses. Brace and Pepper, in their presentation "Impact of Agricultural Drainage on Wildlife", proposed that the following five step management procedure be followed to resolve conflicting wetland uses:

Step 1. identify the interests, agencies and research requirements,
Step 2. define the goals and objectives,
Step 3. inventory and classify the resource,
Step 4. develop a plan for management,
Step 5. implement the plan.

This procedure may be used to develop a multiple use management scheme as well. The papers in Session IV, and in the conference in general, support several of the steps.

For example:

Step 1. Interests.

The conference has assembled many of the interests and agencies concerned with land drainage. Specific research was identified by several speakers. Two outstanding examples are Gaboury in his address: "The Effects of Land Use Changes and Activities on Walleye Reproductive Success in the Valley River" and Gray in his interesting groundwater study "The Modification of Artesian Aquifers to Enhance Agricultural Drainage Systems".

Step 2. Goals.

Goals were addressed generally, for example, the preservation of soil fertility for future generations, but not in terms specific enough to be used in a management plan.

Step 3. Inventory.

Rump and Rubec in their paper "Prime Wetland Land Use Monitoring Activities and Needs in Southern Canada" and Osborne in his paper "Wetlands: Their Role in Prairie Water Flow Systems and Soil Development" presented the major components of an inventory, classification and monitoring system for land and water uses.

Step 4. Plan.

No overall management plan was proposed for western rivers.

Step 5. Implementation.

Professor Leitch suggested six ways in which confliciting uses of aquatic resources can be resolved in his paper "Prairie Potholes and the Prairie Farmer". In order of increasing severity, they were (1) education, (2) social pressure, (3) economic incentives, (4) tax credits, (5) economic penalties and (6) prohibitions. Rossillon, in his dynamic presentation "Make Your Wetlands Work for You" illustrated how the first three ways could be used effectively.

In total, the speakers in Session IV and in other sessions demonstrated that there are methods, supported by a broad base of farm experience and academic studies, that could successfully integrate agricultural drainage in a multiple use management scheme for soil and water resources.

Recommendations

Two missing components of the proposed management scheme were:

2. specific goals and objectives
4. a multiple-use plan.

Supplying these components is not an insurmountable task. The problem is, what group or collection of governments and agencies have broad enough terms of reference to define the goals and to produce an integrated plan on a river basin-wide planning and management river authority for each of the major river basins that drains from the western provinces. This is both the physical and administrative level at which successful integration might be achieved.

Thank you for the opportunity to hear and comment upon these many interesting presentations.

REPORTS FROM WORKING GROUPS

Farmers and Agricultural Organizations Group Leader - Joe Omichinski

During the course of the group discussions, the farmers and agricultural organizations agreed to hold a joint session. The results of their discussions are summarized below:

1. The answer to question 1 is "yes" recognizing that each crop reacts in a different way.
2. The answer to question 2 is "no" both from a farmer viewpoint and from an engineering viewpoint. As a general rule "store - don't drain".
3. It is not likely that the effects of drainage can be known. An example of why this is so can be seen in the inability to predict weather and more important, we cannot predict future weather patterns.
4. In answer to question 4, it was agreed that compromise is required between all groups concerned. For example, cooperation between government agencies could result in a government program to purchase wetlands.

Municipal Councillors Group Leader - Dave Harms

Municipal councillors and local organizations were of the view that we do know the effect of excessive soil moisture on various crops. They also responded in the affirmative to the question dealing with whether or not we know enough to build effective drainage works.

The general feeling was that a conference of this nature needed greater participation by farmers. Indeed, the development of appropriate practises as outlined in the paper by Al Chambers suggests strongly that farmer participation in conferences like this are an essential element. There is a need to coordinate the input of all agencies in arriving at integrated solutions on a regional basis. This coordinated approach will be essential if the benefits of appropriate land and moisture management are to be enjoyed 200 years hence. We must expand our education programs in our rural schools, so that the concepts of comprehensive resource management are more fully understood by those who will work on farms, but also by those who will make land use decisions related to farm lands.

A conference in early December, 1983, namely; The International Coalition for the Red River, was held at Grand Forks. This conference had widespread representation of public groups, farmers, watershed managers and could serve as a model for the mix of people that would be most desirable at future conferences in this series. Indeed, a conference which is organized to provide more local input, must also provide a program which better meets the interest of farmers and local groups.

The incentive structures need to be modified. This means that revisions to the Wheat Board, local and provincial tax structures are required. Tax incentives through assessment reductions are necessary to support improved land management. We must be careful in our efforts to save land that we do not create massive bureaucracy. It is possible to save millions of acres of land without creating enormouns bureaucracy. This has been done by others and can be done again.

The group developed two statements as follows:

I. WHEREAS Soil and water management are mutually interdependent, and,

WHEREAS it can be demonstrated that the proper land management practices can have a beneficial effect on rates of runoff, sedimentation, groundwater recharge and water quality, and,

WHEREAS revisions to existing institutional structures - Canadian Wheat Board quota regulations, municipal tax quota regulations, municipal tax notice details, etc., could encourage landowners to adopt proper management practices at a minimal cost in public funds.

THEREFORE BE IT RESOLVED THAT the participants at the Third Annual Western Provincial Conference on the Rationalization of Water and Soil Research and Management urge the premiers of the Western Provinces to use their influence to ensure that these changes are made in institutional structures.

II. WHEREAS it is in the best interest for future generations to enjoy equal opportunities in the farming and land-use industries, and,

WHEREAS goals would now be set to improve and enhance the condition of our soil and water resources.

THEREFORE BE IT RESOLVED THAT we ask the premiers of the Prairie Provinces to embark on a program that would coordinate all interest groups and agencies associated directly or indirectly with soil and water management program on a regional or district basis, with the goal in mind that 50 or 100 years from now, our children and our children's children can still enjoy and profit from an environment as good or as better than what ours is today.

Provincial Agencies and Universities Group Leader - W. R. (Bill) Newton

I recently heard one of our TV comics give his definition of a "Canadian". According to him a Canadian is the kind of person who stands on the street corner at 4:00 in the morning when there is not a vehicle in sight or a policeman within 10 blocks, who knows he can cross the street in safety and with impunity yet stands and waits for the "walk" signal.

Though I cannot necessarily agree with that definition, it does seem to me, after sitting here for the last couple of days listening to something like 30 very fine papers and knowing that we have had a hundred years of experience in our various fields and that we have available to us the results of the study and research of any number of scientific groups and of many good men, that we should hence have enough knowledge in each of our separate disciplines to allow us to now proceed collectively, with reasonable assurance of success and with a good degree of impunity, to develop and deliver programs directed at the resolution of most of our land resources problems in each of our regions, yet we still seem to be standing at the 1890's crossroads waiting for the "go" signal. This was also my impression of the gist of the discussions within my group in addressing your four questions.

Mine was an extremely large group. It was consequently difficult in the short time available to ensure that all views on each question were adequately heard and assuredly there was not opportunity for debate on varying views. I will however, endeavor to present my impressions of what I believe was the general consensus resulting from the discussion of each of the questions.

Question 1 "Do we know the effect, quantitatively, of excessive soil moisture on various crops?"

The soil scientists at our universities, in the private sector and those working in various levels of government have conducted research and studied the problem to the extent that there should be sufficient knowledge to now make adequate quantitative judgements relative to most soil and most crops and to apply this knowledge in the field in the regulating of specific conditions for an optimum balance.

At the same time, the group resolved that there is a continuing need to fine-tune the information currently available and to this end the group recommended increased support for research both in the laboratory as well as for practical application in the field.

Question 2 "Do we know enough of the physical parametres of soil moisture movement to design effective and efficient works to reduce excessive soil moisture?"

It was considered that sufficient theoretical information was available both in respect of defining the parameters and in the matter of the kinds of works that might be successful in controlling and modifying moisture movement. The problem is considered to be availability of information as to the field application of these theories and these suggested methods. This can only be obtained through concerted programs applying this knowledge and these theories to "hands on" situations under field conditions.

The group recommends collective application of current knowledge to the resolution of specific problems in each of the areas and each of the regions of the western provinces. It is further suggested that a method of information exchange between people working on these problems in each of these regions be established so that the mistakes made need not be repeated in each region and so that each might benefit from the successes of the other. There is a need to expand soil survey activities to gain more knowledge in this matter and to undertake innovative approaches to the handling of moisture excesses and moisture movement, such as for example, that suggested by Mr. Lock Gray in his paper.

Question 3 "What is required to enhance our ability to quantify the effects on the environment, in economic terms, of reducing excessive soil moisture by land drainage?"

This question promoted as many opinions as there were people in the room and a cross-section of that group included economists, agronomists, engineers, soil scientists, biologists, representatives from universities, various government agencies, Ducks Unlimited, etc. Concerns were expressed as to the penchant for defining values entirely in economic terms. It was felt that present methods of defining costs and benefits have been addressing the situation in respect of the limited conditions confined by the present and are not adequate when addressing problems of the entire environment or the needs of good stewardship.

Some elements are not readily defined in dollar terms, vis-a-vis wildlife, wetlands and even aesthetics (which is a vital element in providing a livable state) and hence are placed in an unfair or disadvantageous position when the "dollar value" approach is used.

The people who often have to ultimately make decisions in matters such as we are concerned with are the politicians. If we continue to supply them with data to make these decisions based solely on the basis of current economics, their decisions might well have an immediate economic benefit but could certainly be adverse in respect to long-term social and environmental values.

The group felt that the economists could not be faulted for the fact that current methods are not adequate to accommodate judgement of values of the various elements of the environment. However, they did feel that a different decision making process and a broader method of value assessment was necessary if the problems of the past were not to be transmitted into the future. It was recommended that a more definitive method of value assessment be established which did not necessarily employ economics alone; that a more adequate and responsive decision making process be defined taking cognizance of long-term environmental effects of the activities not the least of which is land drainage and one that does not encourage the basing of these decisions on current views and present values only.

Question 4 "How can agricultural drainage be efficiently and effectively integrated with multiple use management of soil and water?"

Since land drainage is one of the engineering functions involved in effective resource management, this question was essentially addressed in terms of engineering as an integral element of multi-use management. It was thus felt that this question is tantamount to asking whether a bridge should be considered as an integral part of the transportation system.

It was also felt that since soil and water are only two of the elements in the environment using the term "soil and water" implies a limited resource application. It was viewed that to resolve the problems we face we should consider lands as the base and "lands management" as the enterprise. Lands management then would be all encompassing and address wetlands, wildlands, recreational lands, etc., as well as farmlands. Only by applying this terminology and this approach will we be truly encouraging the recognition on all of the elements.

An effectively integrated lands management approach should first address the problem using nature's base and that is the watershed as the unit for planning and delivery and secondly should involve all resource disciplines including engineering. The engineer cannot be all things - he is not a biologist, a forester, an agronomist. He needs the collective input of all interested disciplines in the defining of the parameters of that problem which requires an engineering solution whether it be the development of land drainage system, a flood control work or the construction of a storage dam.

To date, the problems presented to the engineer for resolution have often been those most obvious or those defined by the beholder. When our forefathers first came to this country and to this province their objective was to develop the lands for productive use (as they saw it) and in Manitoba they looked at, for example, the vast wetlands in the Red River Valley. They defined their problem (or their objective) as being the removal of the waters from these lands so that crops could be produced. The engineer of the time complied and vast drainage works were put in place and the end result was one of the most productive grain growing areas in the province. In other words, the objective was achieved.

At this date, the municipal official whose concern is for the good and welfare of his ratepayers as he sees it, defines their problem as excess waters or flooding and he takes action with or without the engineer to correct that problem and does so through the direct approach - the building of drains.

We tend to continue to handle our land development problems using an inverse approach. I go hunting in an area between Stead and St. George where five years ago there were large tracts of so-called moose pasture. In the intervening five years I have seen the trees and brush bulldozed and burned and the peat burned off and farming operations begun. The demand in that area now is for drainage works to accommodate the resultant agricultural enterprise and the municipalities are now required to resolve the problem - by constructing drainage ditches. In five or 10 years hence the wildlife people will be asking where have our wetlands gone - where have our wildlands gone. This is not, in my opinion, good lands management. It is a single resource development with short range objectives.

Where new lands are considered for opening up, there must be a new set of objectives addressed - objectives which recognize all resources in the area. This can only be done by all disciplines becoming involved before this kind of development is begun and not in a postmortem position trying to correct an adverse situation after the fact.

My group recommends that land and lands management be the basis for planning program delivery that a more definitive multidisciplinary approach be implemented and that as projects and programs are planned and undertaken in the various regions which we represent, there be some form on information exchange between regions so that the results of the efforts in the separate regions can be applied where applicable in all regions.

Finally, land drainage is a vital element in most land management efforts but is not an end in itself, it is a service to lands and only a means of achieving good lands management practices. It is, therefore, essential that the engineer and his colleagues in all disciplines be involved in defining the problems and their solutions.

In summary then, it is suggested:

a) Although the stated theme of this conference appears to be of a single discipline nature, i.e. the manipulation of water (both surface and subsurface) to enhance the productive capability of agricultural soils, the papers presented produce a hidden agenda based on a theme which is multidisciplinary in nature.

b) Lands management in all its aspects should be the basis for future action with the objective of conserving, preserving, developing and the prudent use of lands (lands being defined as wetlands, wildlands, recreational lands, etc., as well as agricultural lands).

c) The unit for management be the watershed considering the principle that the good welfare of the watershed resources means a healthy watershed environment and that the collective health of all of the watersheds means a healthy whole environment.

d) We cease operating within our separate disciplines and join with our colleagues in other disciplines towards the resolution of common problems.

e) There be a method of exchange of information and technology between regions so that each region may benefit from the knowledge gained in and the successes achieved by other regions in resolving similar problems. This might well be achieved through the establishment of a "Lands Management Council" at federal level to act as a collector of and repository for information and technology.

f) There is sufficient information available in the various disciplines to allow us to get on with the job taking a multidiscipline approach to the resolution of our problems. There is however, at the same time and coincident with action programs a need for continued research so as to improve the information available and to add to this body of information that gained through action programs. Research is also necessary in order to develop new technology and new strategies to accommodate future demands and requirements.

Federal Government Agencies Group Leader - Kent Brace

Question 1 "Do we know the effects, qualitatively, of excessive soil moisture on various crops?"

NO

Need to know more about:

1. Perennial crops that can withstand excess water.

Question 2 "Do we know enough of the physical parameters of soil moisture movement to design effective and efficient works to reduce excessive soil moisture?"

Require interdisciplinary approach to assess design parameters and develop appropriate drainage coefficients.

Question 3 "What is required to enhance our ability to quantify the effects on the environment, in economic terms, of reducing excessive soil moisture by land drainage?"

Require: a) an inventory of wetlands

b) indices to determine which wetlands can or cannot be drained.

Question 4 "How can agricultural drainage be efficiently and effectively integrated with multiple use management of soil and water?"

Require a Task Force to draw together various disciplines to develop a logical approach to water management.

A clearer message regarding land drainage and its effects on all related resources must be sent to all those concerned.

POSTER SESSION PAPERS

Mole Drainage for Reclamation of Irrigated Saline Soil

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Mole drainage has been successfully used in England since the 18th century to drain wet land (Hudson et al., 1962) but its use for reclamation of waterlogged saline land is uncommon. The effective life of mole drains varies from days to decades (Nicholson, 1946). At time of installation, soil moisture and soil texture are critical factors for stable mole drains (Childs, 1942; Raadsma, 1974; Spoor et al., 1982a,b). Mole stability can be further improved by installing plastic linings (Dylla et al., 1963; Fouss and Donnan, 1962).

Laboratory and field studies have been conducted at the Lethbridge Research Station to determine suitable soil conditions for installing durable mole drains and to determine field performance of unlined and lined mole drains.

Materials and Methods

Laboratory Study

The torpedo used to form the moles was 19 mm in diameter and 50 mm long. A cable (2-mm diam.) was attached to the bullet-shaped nose and a hand-powered winch, fastened to a bench, was used to pull the torpedo through the soil. The soil bins used were 300 mm square and 330 mm deep (Fig. 1). A port, 33 mm diam. and 80 mm above the base (at center), was centrally located at each end. The torpedo was pulled through these ports.

Three subsoils were used for this experiment - a loam, a clay loam, and a clay. In preparation for the tests, the soils were air-dried and crushed to pass an 8-mm sieve.

Mole performance was determined in triplicate on each soil at six soil moisture levels: AD (air-dry), 025 FC, 0.50 FC, 0.75 FC, FC, and 1.25 FC (FC=moisture content at 20 kPa suction). The bulk density of each soil for all moisture levels was approximately 1.5, 1.4, and 1.3 for the L, CL, and C, respectively, similar to field conditions. The channel left by the torpedo was examined for stability. To determine the durability of the moles, the bin was dropped three times from a height of 50 mm onto a solid block and the channel was re-examined for stability.

The stability of the moles in the soils at FC moisture level was further evaluated by leaching water (continuous head, 1 cm) through the soil into the channels and out through the ports for as long as 14 days. Durability of the channels was determined visually.

Field Study

The site, 100 x 200 m, was on a dominantly saline, poorly drained, clay loam soil over till, near Taber, Alberta. Saline-sodic soil was also present at the site.

Mole drains (92-mm diam.) were installed in 1968 at 0.7-m depth with a mole plough (Fig. 2) Perforated 20-mil PVC plastic (30-cm wide), notched on the edges, was used in the lined drains. As the lining was fed through an attachment to the mole plough, it folded to form a tube and the notches on the edges interlocked to retain the tube shape. Three drains of a kind were installed in a block which ran from bottom to top of the slope (Fig. 3). There were four blocks, each of unlined (U) and lined (L) mole drains randomly paired across the site, and three check blocks (C) with no drains, one at each end and one in the center of the site. Across the middle of the site, a row of 43 groundwater observation wells, of 2-cm perforated iron pipe, was installed to monitor groundwater depth at prescribed times using a pneumatic sounder.

Reclamation Procedures and Drain Performance

The groundwater level was raised to ground surface by flooding; groundwater was then drained away while the drain discharge and water table recession was monitored. This procedure was carried out once in 1969, and at 2- and 3-week intervals during the irrigation season (5 to 7 times) from 1970 to 1979. To saturate the profile, the site was flooded from 5 to 6 h on one day to raise the water table to ground surface and again for about 3 h on the second day. The net amount of water applied (total minus runoff) at each flooding cycle was 23 to 15 cm. The average annual net application was 77 cm plus an annual average of 16.5 cm precipitation during the flooding season.

Drain discharge was measured with a calibrated vessel and stopwatch at termination of flooding on the second day and at 9, 18, 29, 46, 70, and 166 h later. Groundwater depths across the site were measured at the same time.

Hydraulic conductivity (K) values were determined with discharge data at 9 and 18 h (U.S. Bureau of Reclamation (USBR), 1978). Optimum drain spacings to achieve a specific drainage rate were calculated, using the transient flow method (USBR, 1978) and k values from drain discharge data.

Results

Laboratory Study

Stable moles were obtained only in the clay loam and clay soils where the soil moisture levels were at 0.50 FC or more (Table 1). When subjected to leaching, the moles in the loam soil collapsed within 1 h after the water was applied. However, the moles in the clay loam and clay soils remained fully open and operative for the duration of the 14-day test.

Field Study

The mean annual rate of peak drain discharge increased from 1969 to a maximum in 1974 for both the unlined and lined moles, except in 1971 (Fig. 4). Thereafter, the rate decreased annually to time of termination of recording, 1979. Throughout the study, discharge from the unlined moles was less than that from the lined, the overall average being 24% of that from the lined drains.

Drain discharge during a flooding-leaching cycle decreased exponentially with time until it stopped after about 70 h (Fig. 5). Initially, the rate at which the discharge approached zero was greater for the lined than for the unlined drains. But, after 46 h, the discharge from the unlined and lined drains was similar.

The average K values of the soil as determined by the drain discharge method at 9 h, which measured vertical, radial, and horizontal (to effective drain depth) flows, the K values were 0.07 and 0.22 cm/h for unlined and lined moles, respectively (0.05 and 0.12 cm/h at 18 h).

The calculated hypothetical drain spacings for this soil using K values from lined mole drain discharge data (at 9 h) were 6.0 m for a water table recession of 35 cm (half of drain depth) in 24 h, or 7.5 m for a recession of 41.45 cm in 29 h as observed. With K values from the unlined moles, the distance became 3.4 m for a water table recession of 35 cm in 24 hr, or 4.0 m for a recession of 37.19 cm in 29 h as observed. Thus, at 29 h the calculated spacing for the lined drains was essentially the same as that of the installed drains, while that of the unlined drains was 0.8 times that of the installed.

Discussion

These laboratory results indicate that, when installing mole drains, the soil should contain sufficient moisture to be plastic, that is 0.50 FC or wetter, and contain sufficient clay (CL texture or finer) to be plastic and cohesive for forming stable moles.

Both the unlined and lined moles were effective for draining this land to satisfactory depth within 24 to 48 h, though the unlined moles seemed to have restricted capacity. The assumption is that the unlined drains were partially plugged by material falling from around the mole, possible in the first year after installation, which caused the limited capacity. However, these partially collapsed drains provided sufficient drainage to be effective throughout the length of the experiment. Lining the moles greatly increased their performance - in discharge, radius of influence, and apparent extended durability.

Though the study was terminated after 10 years of intensive leaching, the data suggest the drains would have functioned longer, especially those that were lined. How much longer is unknown.

The conclusions from this study are that mole drains can be effective in draining land which had become salinized and waterlogged because of poor natural drainage, providing soil conditions and moisture content at time of installation are suitable. Lined moles were most effective. If soil conditions are favorable, there are economic advantages to mole drainage because of the low cost of installation relative to other kinds of subsurface drainage.

References

Childs, E. C. 1942. The mechanics of mole drainage. Emp. J. Exp. Agric. 10: 169-181.

Dylla, A. S., Rollins, M. B. and Meyers, V. I. 1963. Experimental plastic drains in Nevada. Nevada State Exp. Sta., Reno, Nevada. Bulletin 228.

Fouss, J. L. and Donnan, W. W. 1962. Plastic-lined mole drains. Agric. Eng. 43: 512-515.

Hudson, A. W., Hopewell, H. G., Bower, D. G. and Cross, M. W. 1962. The draining of farm lands. Massey College, Palmerston, North, New Zealand.

Nicholson, H. H. 1946. The principles of field drainage. Cambridge University Press, London.

Raadsma, S. 1974. Current drainage practices in flat areas of humid regions in Europe. Pp. 115-143 in J. van Schilfgaarde (ed.) Drainage for Agriculture. No. 17, Agron. Series, Amer. Soc. Agron. Inc., Madison, Wisconsin.

Spoor, G., Leeds-Harrison, P. B. and Godwin, R. J. 1982a. Some fundamental aspects of the formation, stability, and failure of mole drainage channels. J. Soil Sci. 33: 411-425.

Spoor, G., Leeds-Harrison, P. B. and Godwin, R. J. 1982b. Potential role of soil density and clay minerology in assessing the suitability of soils for mole drainage. J. Soil Sci. 33: 427-441.

U.S. Bureau of Reclamation. 1978. Drainage manual. U.S. Dept. of Interior, Bureau of Reclamation, Washington, D.C.

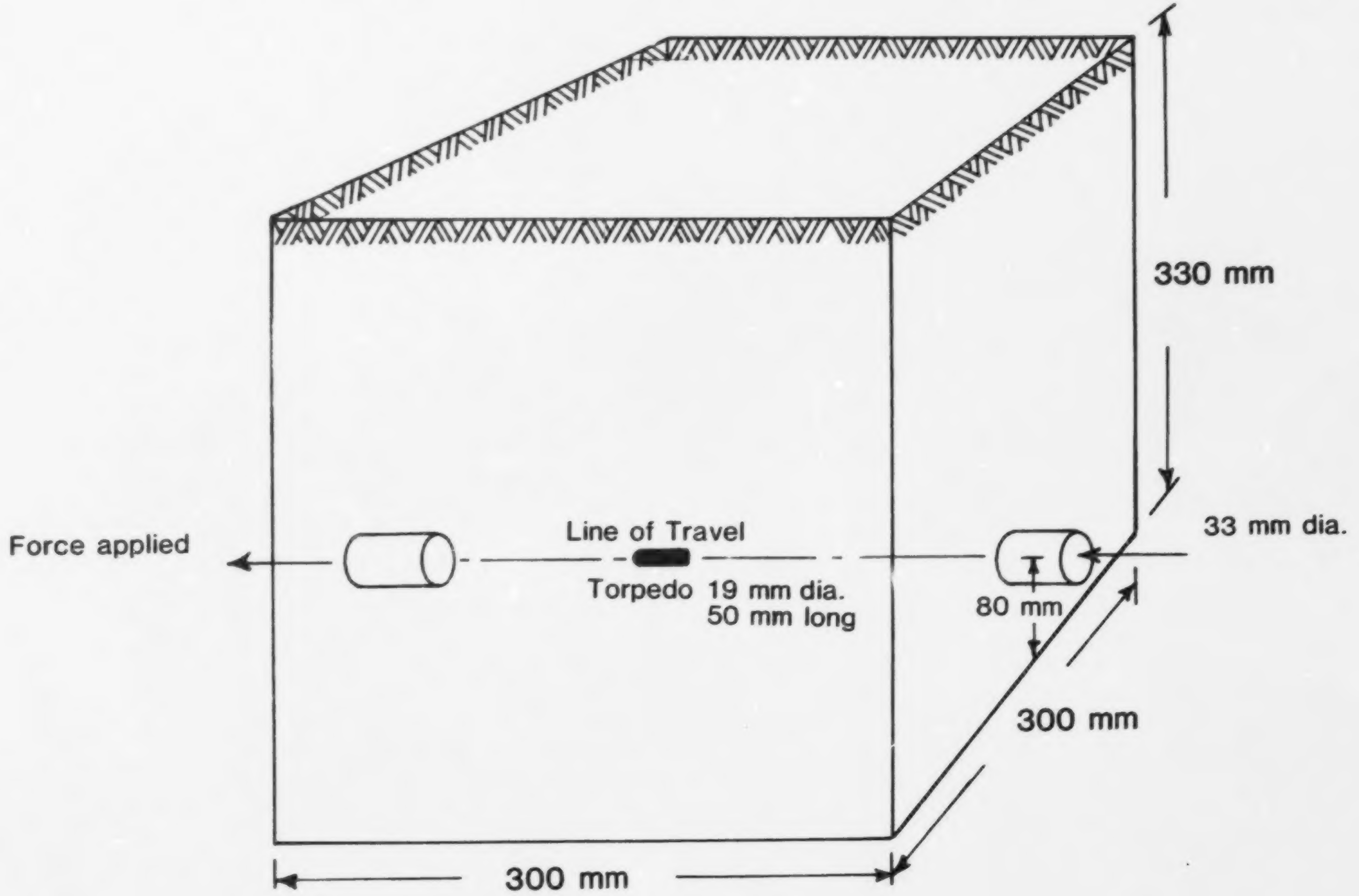

330 mm
33 mm dia.
Force applied
Line of Travel
Torpedo 19 mm dia.
50 mm long
80 mm
300 mm
300 mm

Figure 1 - Soil bin used for laboratory study.

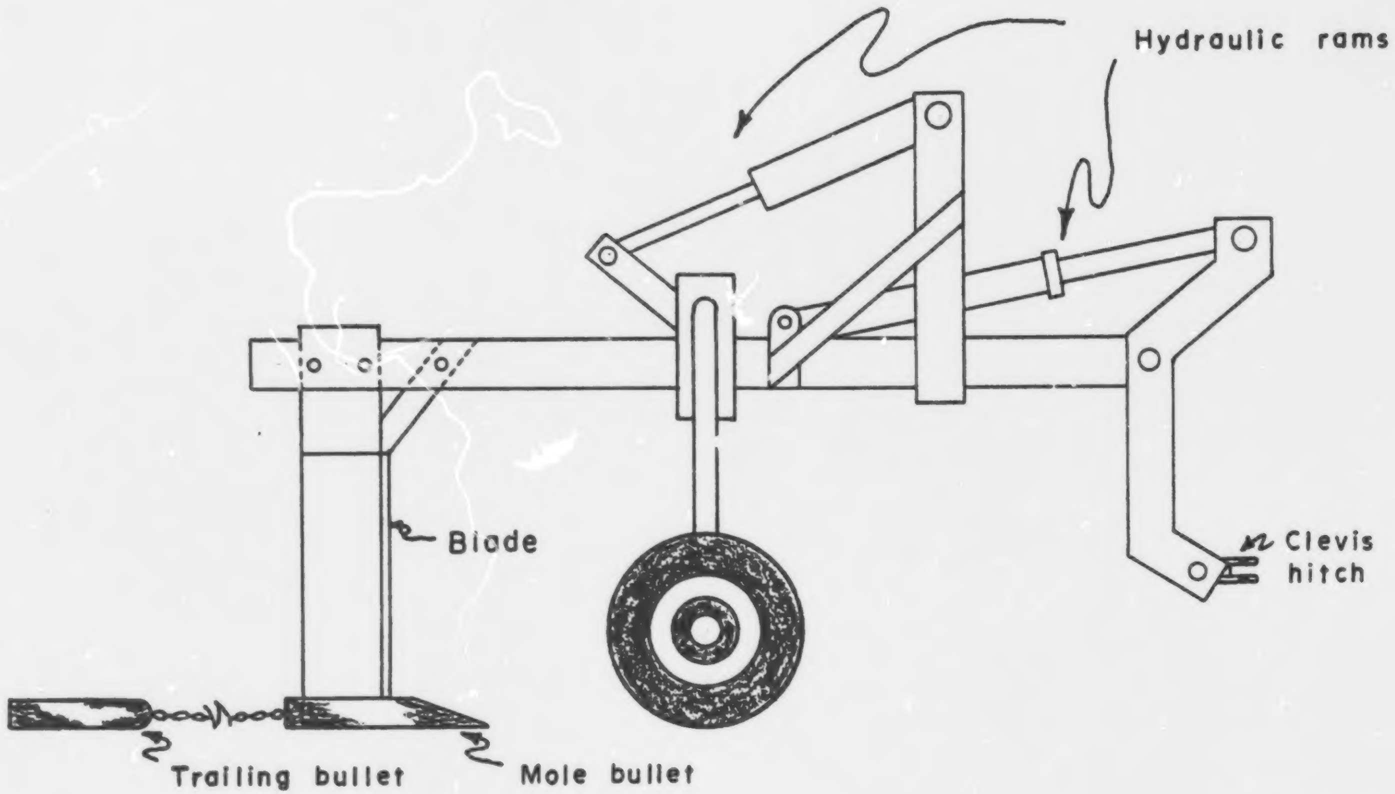

Hydraulic rams
Blade
Clevis hitch
Trailing bullet
Mole bullet

Figure 2 - Schematic of plow used to install mole drains.

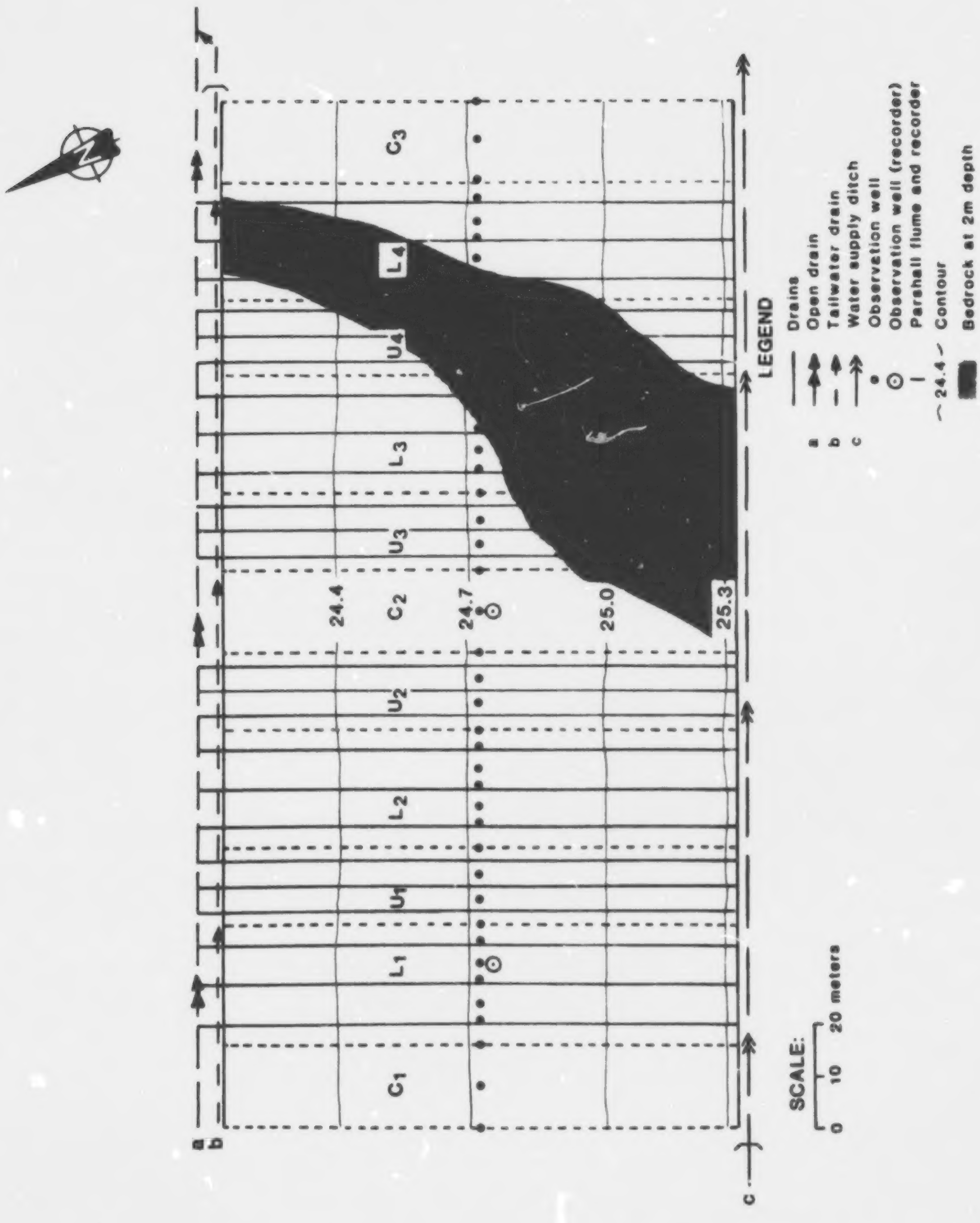

N
a
b
c
C1
L1
U1
L2
U2
C2
U3
L3
U4
L4
C3
24.4
24.7
25.0
25.3
SCALE:
0
10
20 meters
LEGEND
Drains
a Open drain
b Tailwater drain
c Water supply ditch
Observation well
Observation well (recorder)
Parshall flume and recorder
~24.4~ Contour
Bedrock at 2m depth

Figure 3 - Site plan showing check (C), unlined (U), and lined (L) blocks with locations of the shallow bedrock, mole drains, observation wells, open drain (a), tailwater drain (b), and supply ditch (c).

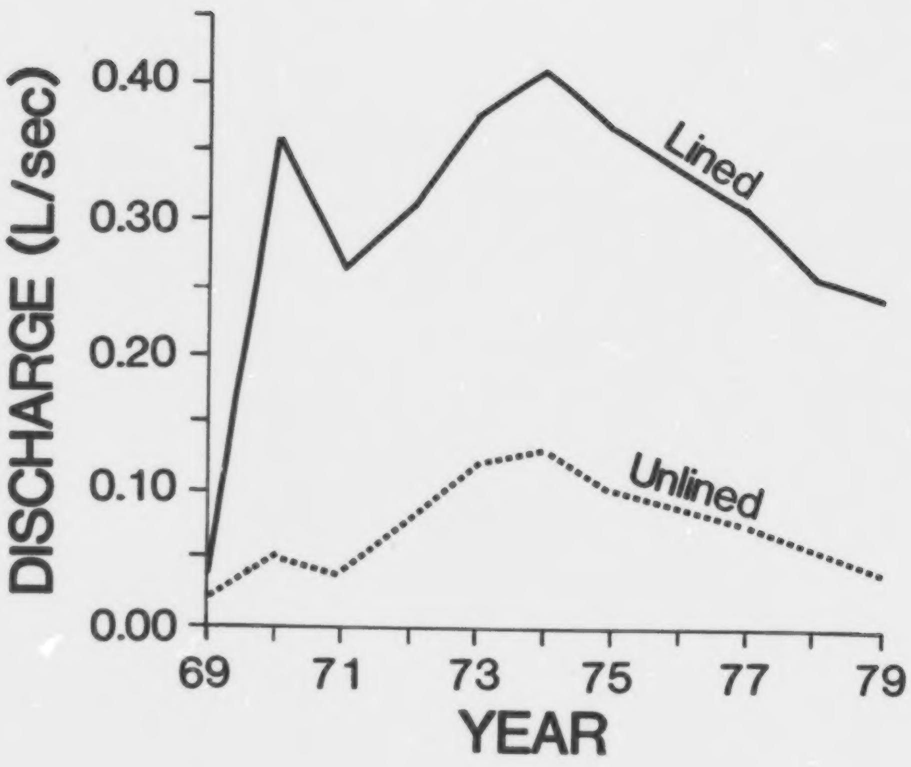


Figure 4 - Average annual peak discharge from the lined and unlined mole drains.

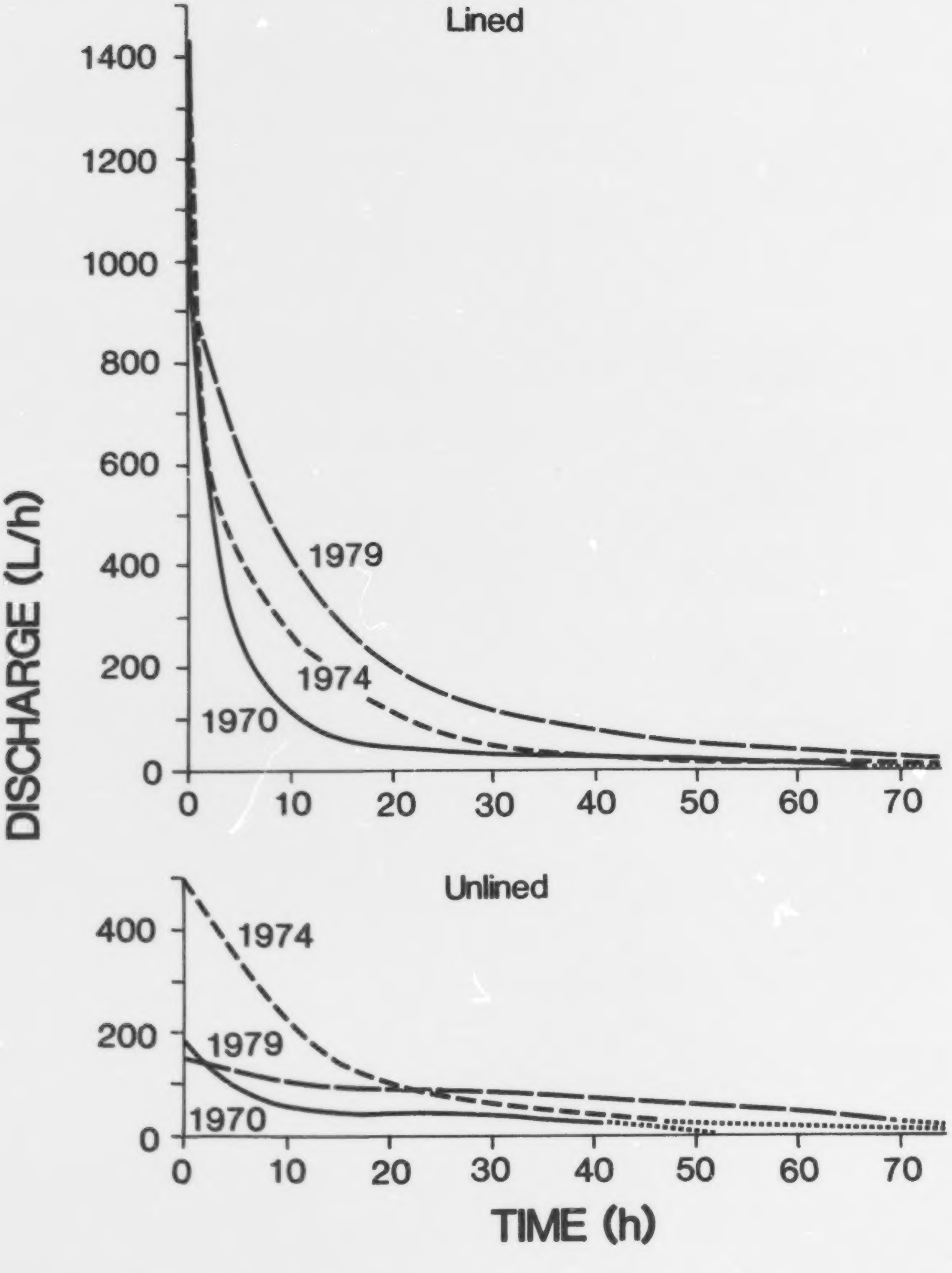


Figure 5 - Drain discharge for lined mole drains from after flooding stopped (0 time) to after drainage stopped, in the years 1970, 1974 and 1979.

Table 1. Visible conditions of moles in L, CL, and C subsoils at different soil moisture levels after forming and after dropping (a distance of 50 mm) three times.

Soil moisture level	L Condition of mole after forming	 dropping	CL Condition of mole after forming	 dropping	C Condition of mole after forming	 dropping
AD[1]	Collapsed	-	Collapsed	-	Collapsed	-
0.25 FC	35% open	Collapsed	35% open	Collapsed	75% open	Collapsed
0.50 FC	Open, smooth surface	Collapsed	Open, rough surface	Open, stable	Open, some surface smear	Open, stable
0.75 FC	Open, smooth surface	Collapsed	Open, some surface smear	Open, stable	Open, surface smear	Open, stable
FC[2]	Open, smooth surface	Collapsed-fragments dislodged	Open, rough surface soil adhered to torpedo	Open, deformed	Wet, plastic	Open, deformed
1.25 FC	Open, but cracked	Collapsed-shattered	Open, surface smear	Open, deformed	Open, flowed shut on standing	-

[1] Air dry.

[2] Moisture content at 20 kPa suction.

SALT DISTRIBUTION IN A SOLONETZIC SOIL AS AFFECTED BY IRRIGATION AND SUBSOILING

C. CHANG AND T. G. SOMMERFELDT

INTRODUCTION

There are 6 to 8 million hectares of solonetzic soil in western Canada (Cairns and Bower 1977) of which about 4 million hectares is in Alberta. Much of this area is farmland (Toogood and Cairns 1978). At least 6 characteristics of solonetzic soils adversely affect their productivity (Cairns and Bowser 1977). The hard, compact B horizon which limits the penetration of water, air and roots is probably the most important character of all to affect crop yield.

Amelioration methods designed to overcome the effects of the hard compact B horizon to impove the productivity of solonetzic soils include deep plowing, adding chemical amendments, and irrigation. All the methods have various degrees of success to improve the chemical and physical properties and productivity of these soils.

Subsoiling is a treatment to loosen soil with narrow tools below the depth of normal tillage without inversion and with minimum mixing of the soil. The advantage of subsoiling over deep plowing is that it will loosen the compact B horizon without mixing the saline-alkali subsoil with the top soil. The effects of subsoiling on soil salinity of a solonetzic soil under both irrigated and nonirrigated conditions are reported.

MATERIAL AND METHODS

Two adjacent fields were selected at the Vauxhall Substation, Agriculture Canada, Vauxhall, Alberta. One field was irrigated and the other was nonirrigated. Each field was divided into 18 blocks and each block was sub-divided into 3 plots, 9.1m X 6.1m in size, for tillage treaments. Treatments 1 and 3, randomly placed in each block, were subsoiled to 52 cm depth in the fall of 1979 and 1980 respectively. Treatment 2 was not subsoiled, as check.

All the plots were fertilized by broadcast at rates of 80 kg/ha/yr of nitrogen and 42 kg/ha/yr of P_2O_5 prior to planting. Neepawa hard spring wheat was grown annually from 1980 to 1983. Two rows of soil moisture tensiometers were installed at 45 cm depth in the irrigated field for scheduling irrigation. A total of 32 cm of water was applied in 1980, 19 cm in 1981, 18 cm in 1982, and 22 cm in 1983.

The soil was sampled in the fall of 1983 at two locations within each plot, 6.1 m apart. They were taken at 15 cm depth intervals from soil surface to a depth of 60 cm and 30 cm interval from

60 to 90 cm at both fields. The soil samples were analyzed for texture, pH of the saturation paste, and Ca, Mg, and Na contents and EC of the saturation extract. The data were statistically analyzed.

RESULTS AND DISCUSSION

The soil texture (Table 1) and salinity (Table 2) in both fields were uniform at the surface but increased in variability with increasing depth. The contour maps of sand contents and EC of the soil at the 0 - 15 cm (Fig. 1 & Fig. 2) and 60 - 90 cm (Fig. 3 & Fig. 4) depths of the nonirrigated field illustrated the texture variability and changes with depth. For example, at 60 - 90 cm depth the sand content changed from less than 30% to greater than 70% within 6.1 m distance. This degree of variability is not uncommon for solonetzic soil. Overall, the soils in the irrigated and nonirrigated fields were similar. The finest texture horizon was at the 30 - 45 cm depth for the irrigated field and 45 - 60 cm depth for the nonirrigated field.

The salinity levels were lower in the irrigated field than in the nonirrigated (Table 2). The EC of saturation extracts at the 60 - 90 cm depth interval in the irrigated field was about 54% or less of that in the nonirrigated field under the same tillage treatments. The lower salinity in the irrigated field is attributed by irrigation which induced the downward movement of soluble salts in the soil profile, even though the annual irrigation rate was just to meet the crop consumptive use. The differences in salinity level among tillage treatments at each depth interval were not statically significant in the non-irrigaed field. However, the differences were statistically significant beween treatment 1 (subsoiling in 1979) and treatment 2 (no subsoiling) in the irrigated field. These results suggest that under semi-arid conditions that subsoiling alone is not a suitable practice to improve this solonetzic soil. Irrigation alone reduced the soil salinity and subsoiling enchanced the reduction.

The sodium adsorption ratios (SAR) of soil saturation extract are shown in Table 3. The SAR values were smaller from the irrigated field than from the nonirrigated. However, the SAR's were not statistical different among the treatments in both fields. The smaller SAR under irrigation suggests that the downward movement of Na was faster than that of Ca+Mg.

CONCLUSIONS

This solonetzic soil, in a semi-arid climate, was highly variable in both physical and chemical properties. Irrigation did improve its salinity and SAR. Subsoiling enchanced the irrigation effects. Subsoiling had no significant effects on the soil salinity and SAR of this soil under nonirrigated conditions.

REFERENCES

Cairns, R. R. and Bowser, W. E. 1977. Solonetzic soils and their management. Agric. Can., Pub. 1391, 37 p.

Toogood, J. A. and Cairns, R. R. 1978. Solonetzic soils technology and management in Alberta. University of Alberta Agric. Bull. B-78-1. 105 p.

Table 1 Soil Particle Size Distribution

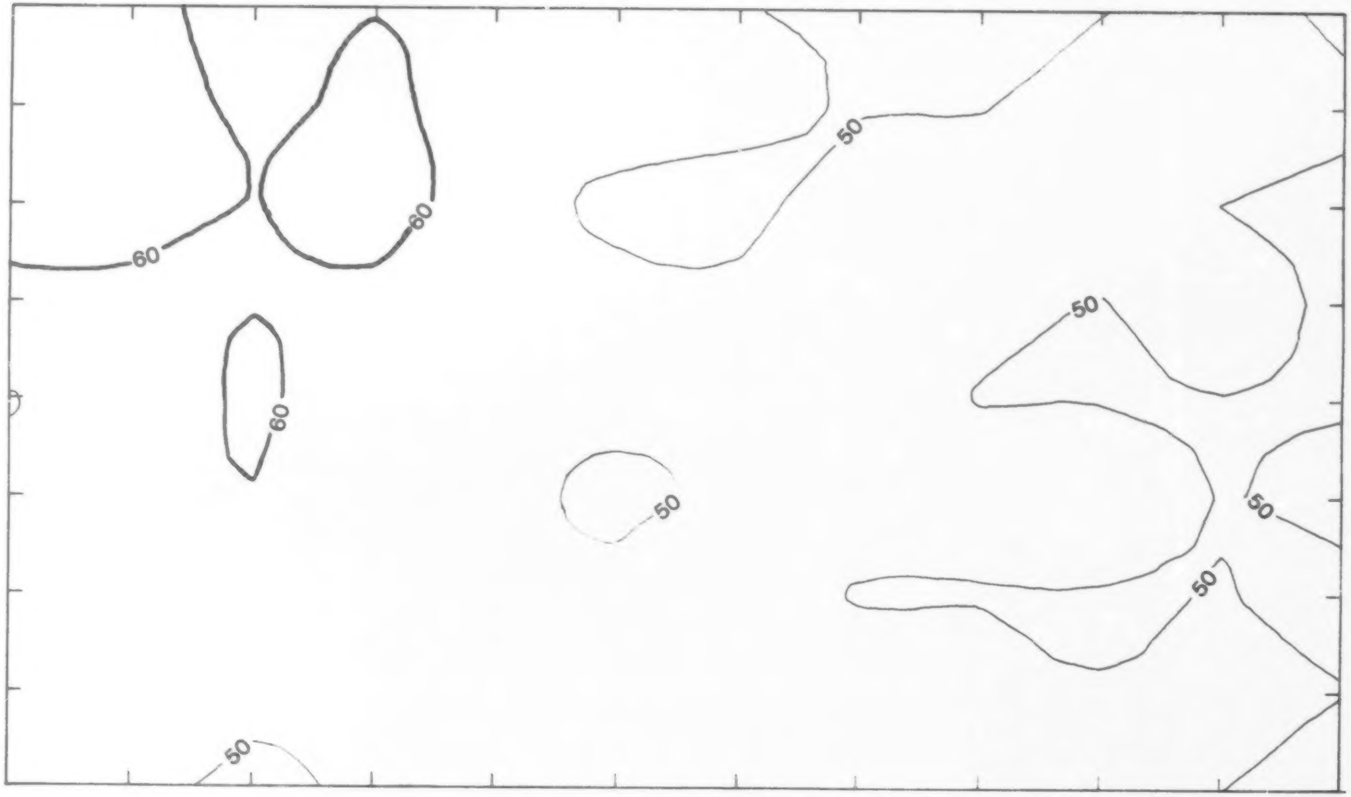
Depth cm	Sand Content %	SD	Clay Content %	SD
		Irrigated		
0-15	55.5	3.58	17.6	2.38
15-30	51.3	8.97	22.6	5.74
30-45	44.0	12.39	26.6	6.81
45-60	46.6	16.33	25.4	8.72
60-90	53.8	18.23	23.1	10.62
		Nonirrigated		
0-15	54.0	6.60	17.6	3.39
15-30	53.4	9.49	22.7	7.22
30-45	47.4	11.35	26.5	8.33
45-60	44.4	13.59	29.4	9.18
60-90	48.2	16.24	27.4	11.44

Table 2 Electrical Conductivity of Soil Saturation Extracts

Depth cm	Electrical Conductivity dS/m					
	Treatment					
	1	SD	2	SD	3	SD
	Irrigated					
0-15	0.89	0.15	1.00	0.24	1.20	0.80
15-30	1.35	1.82	1.66	1.90	1.15	1.23
30-45	2.14	3.06	4.11	4.35	2.63	3.49
45-60	2.36	2.83	5.75	5.48	3.55	4.69
60-90	3.94	4.36	7.06	6.85	4.77	4.78
	Nonirrigated					
0-15	1.32	0.85	1.49	0.90	1.48	1.03
15-30	3.25	2.97	4.48	5.38	3.29	4.07
30-45	8.84	6.49	10.58	8.83	8.98	7.90
45-60	11.46	6.61	12.96	7.86	11.32	8.16
60-90	12.64	6.28	12.99	5.97	11.85	7.38

Table 3 Sodium Adsorption Ratio (SAR) of Soil Saturation Extract

Depth cm	SAR		
	Treatment-1	Treatment-2	Treatment-3
	Irrigation		
0-15	1.07	1.05	1.14
15-30	1.91	2.38	2.21
30-45	3.08	4.42	3.11
45-60	4.54	6.38	4.45
60-90	8.29	10.01	7.60
	Nonirrigated		
0-15	1.33	1.37	1.51
15-30	3.62	3.71	3.15
30-45	7.05	7.62	5.40
45-60	12.54	12.86	10.00
60-90	17.30	15.64	14.98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50

Fig. 1 Contour map of sand content 0 - 15 cm nonirrigated

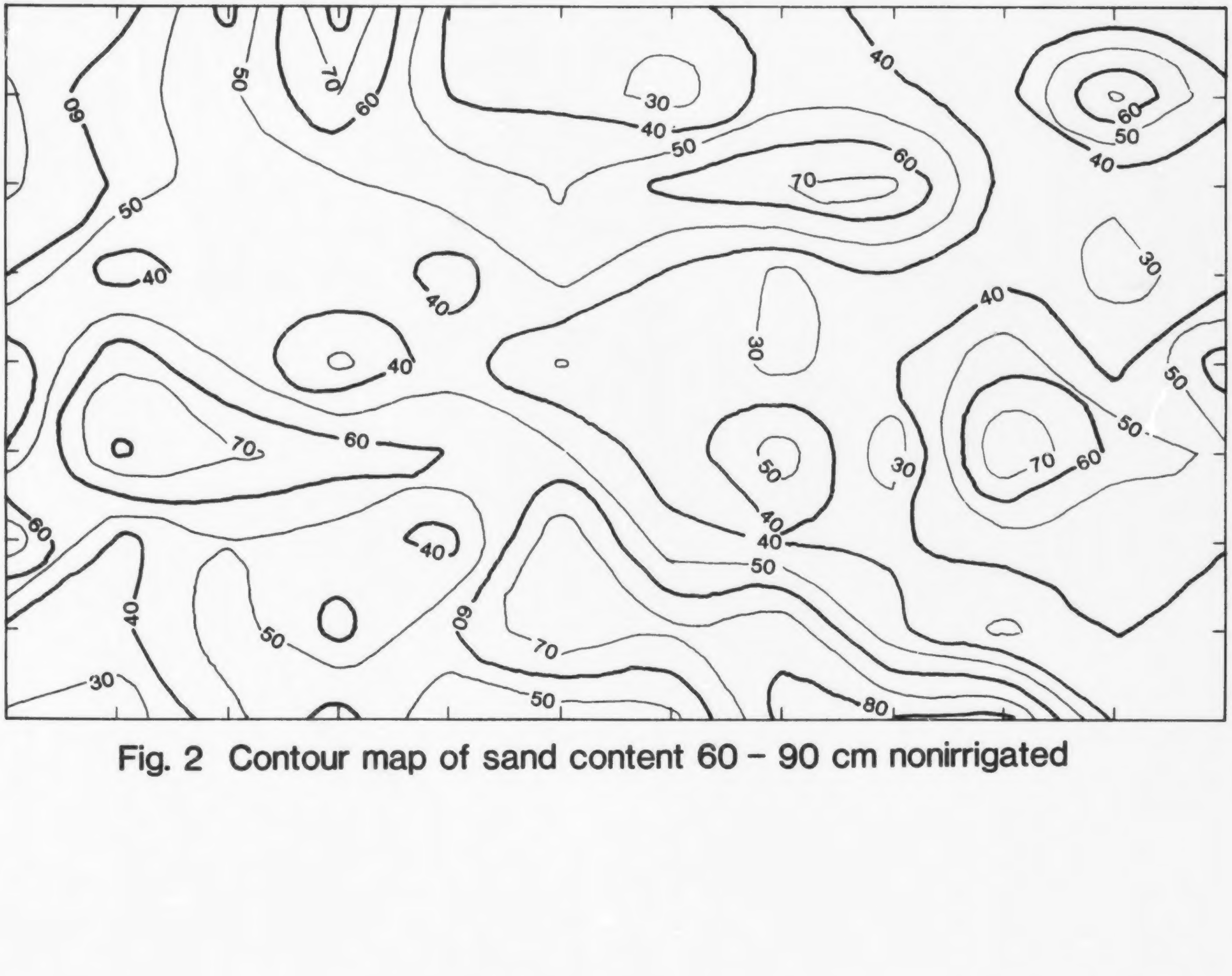

30
40
50
60
70
80

Fig. 2 Contour map of sand content 60 – 90 cm nonirrigated

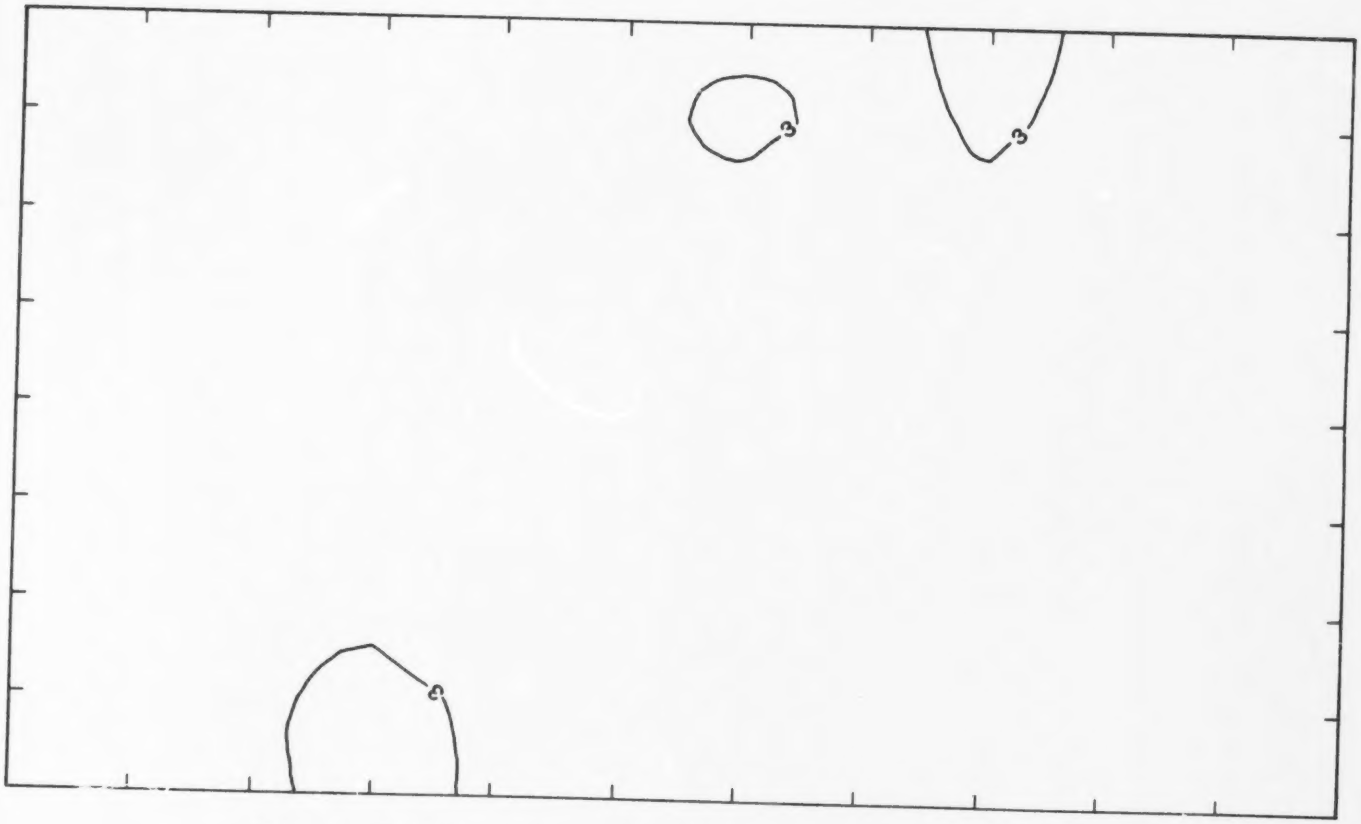
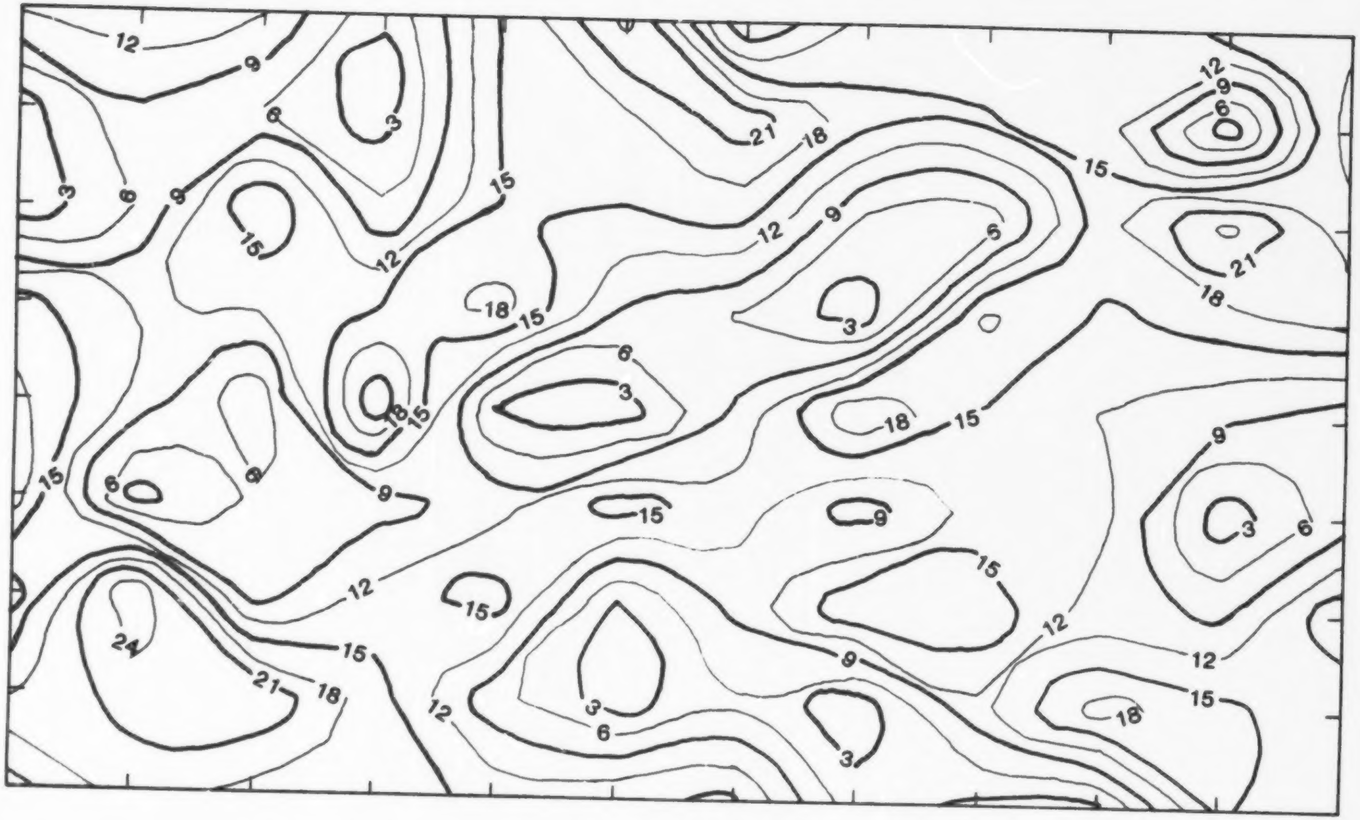


Fig. 3 Contour map of EC 0 – 15 cm nonirrigated


12
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18

Fig. 4 Contour map of EC 60 - 90 cm nonirrigated

SOME MAJOR FACTORS IN SALINITY RECLAMATION RATES

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For presentation at the Poster Session
of the 3rd Annual Western Provincial
Conference, "Agricultural Land Drainage"

The Fort Garry Hotel
Winnipeg, Manitoba

November 20 to 22, 1984

INTRODUCTION

Subsurface drainage in southern Alberta is usually installed to facilitate reclamation of saline soils. By lowering water tables and serving as salt outlets, the drains extricate salt leaching from the root zone. The rate at which the reclamation process occurs determines the rate of increased productivity and potential economic return. As identified by a province-wide survey of soil research personnel, the fourth ranked of fifty-seven "critical needs" in salinity research was "Development of post reclamation management practices for drained soils including required leaching and anticipated reclamation rates after drainage" (Harker, 1984).

This paper examines four key factors affecting reclamation rates in Alberta soils. These factors are:

1) target depth of soil to be reclaimed,
2) water applications for leaching,
3) consumptive use of saline groundwater, and
4) salt load buffering in a sulfate dominated soil system.

Because of the simplistic nature of some of these factors, they are easily overlooked.

FACTORS 1 & 2

Target Depth of Soil to be Reclaimed and Water Applications for Leaching

What depth of soil must be freed from salt before reclamation is adequate or complete? To help answer this question a greenhouse experiment was conducted to determine the effect of the depth of non-saline and weekly saline soil over strongly saline soil on barley grain yields. Layers of two soils having an electrical conductivity (EC) of 1.2 and 4.7 mS/cm were placed over soil having an EC of 22.2 mS/cm. The 1m deep, 15 cm diameter soil columns were cropped to Galt barley. Figure 1 shows the barley yields increasing with increasing depth of non-saline and slightly saline soil over the strongly saline material. The regression line infers that yields comparable to the non-saline control would be had with 94 cm of non-saline and slightly saline material.

In some cases, trafficability afforded by subsurface drainage is acceptable reclamation in the farmer's view. Any yield increase is a bonus. A farmer accustomed to no yield may be pleased with 50% yield of maximum. The farmer - researcher - extension team should establish target reclamation depths (hence yields) since different water management will be required for reclamation of different depths.

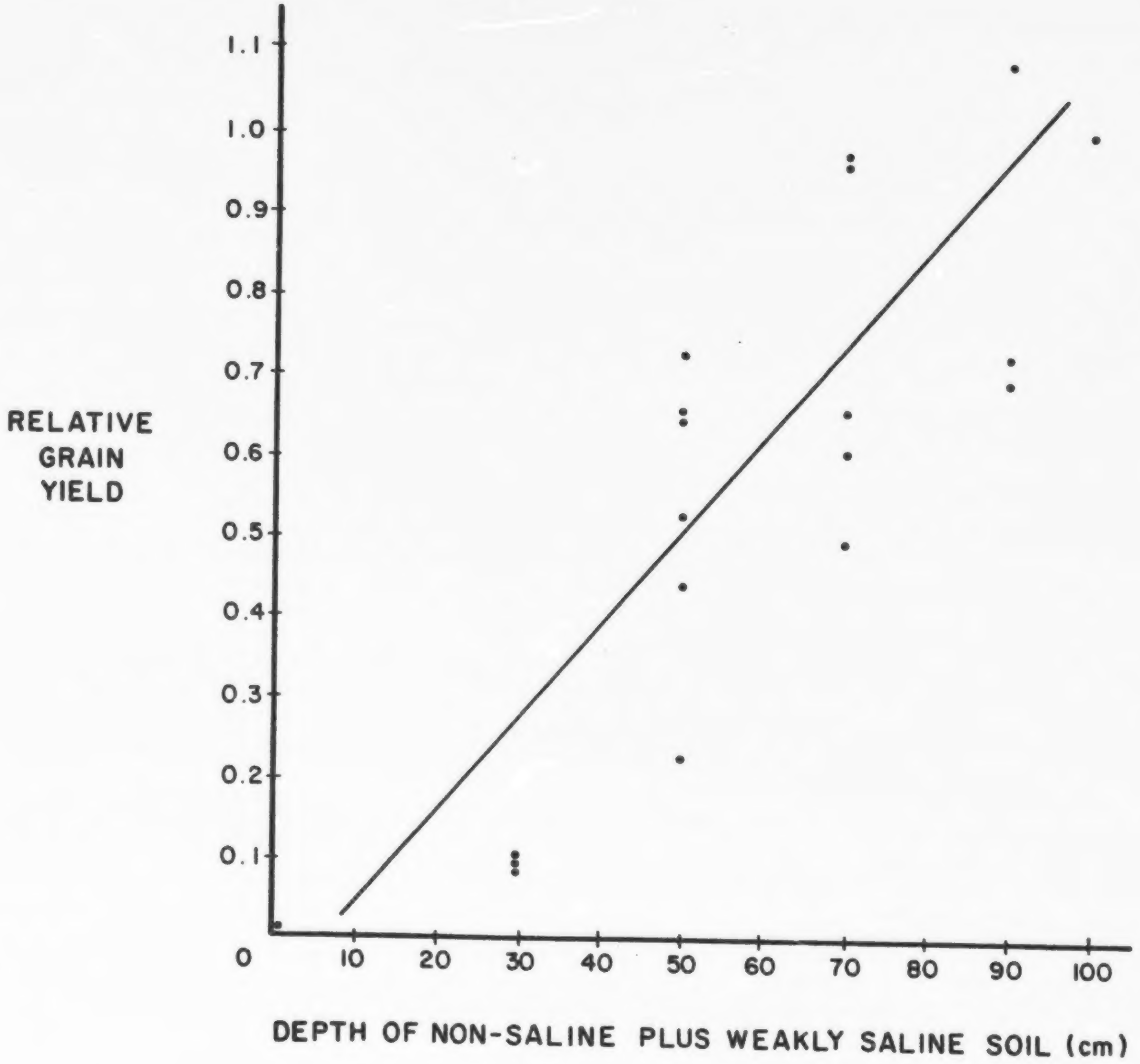


FIGURE 1. BARLEY GRAIN YIELDS AS AFFECTED BY DEPTH OF NON-SALINE PLUS WEAKLY SALINE SOIL OVER STRONGLY SALINE SOIL.

$y = -0.089 + (0.0116)(x)$, $r^2 = 0.62$

y = RELATIVE YIELD

x = DEPTH OF NON-SALINE PLUS WEAKLY SALINE SOIL OVER STRONGLY SALINE SOIL(cm).

A simple equation from Hoffman (1980) helps illustrate the interaction of soil depth to be reclaimed and leaching water applications:

$$\frac{C}{Co} = (0.1)\ \frac{DS}{DIW} \qquad [1]$$

C = EC of soil after leaching
Co= EC of soil before leaching
DS= depth of soil being reclaimed
DIW= depth of applied water for leaching

A plot of equation [1] is given in figure 2. This equation can be used to describe the reclamation process in a general way when water applications occur intermittently. For the complete reclamation of 1m of strongly saline soil, water applications totalling in the order of 1 metre would have to be applied. To reclaim only 50 cm of the profile would require only 50 cm of applied water. Typical quantities of water applied by Alberta irrigators are 20 to 30 cm of water in a season. Assuming no consumptive use, these applications would reclaim only 20 to 30 cm of strongly saline material in addition to that reclaimed by rainfall. If evaporation or transpiration removed any of this applied water then the reclamation rate would decline proportionally. Van Schilfgaarde et al. (1974) give a simple equation that illustrates this. The volume of irrigation water plus rainfall that must be added to the soil to maintain a salt balance, note, to maintain not to diminish root zone salt levels, is given by:

$$Viw = \frac{Vcu}{1-LR} \qquad [2]$$

Viw = volume of irrigation water plus rainfall
Vcu = volume of consumptive use
LR = leaching requirement as calculated below

$$LR = \frac{ECiw}{ECdw} \qquad [3]$$

LR = leaching requirement
ECiw = electrical conductivity of the irrigation water
ECdw = electrical conductivity of the drainage water below the root zone

Viw will always exceed Vcu, i.e., for reclamation to occur water applications must be in excess of consumptive use within any given zone. Traditional irrigation practices (Pohjakas and Kearns, 1980) will not provide adequate leaching water if the soil being reclaimed supports crop growth which uses that applied water for consumptive requirements. The rate of reclamation of any given depth of soil depends on the amount of leaching water passing through that depth of soil in a given time period. Reclamation will not occur if inadequate water is applied. "Salinity can never be effectively controlled by merely lowering the water table if insufficient water passes through the soil to leach it" (Arar et al., 1970).

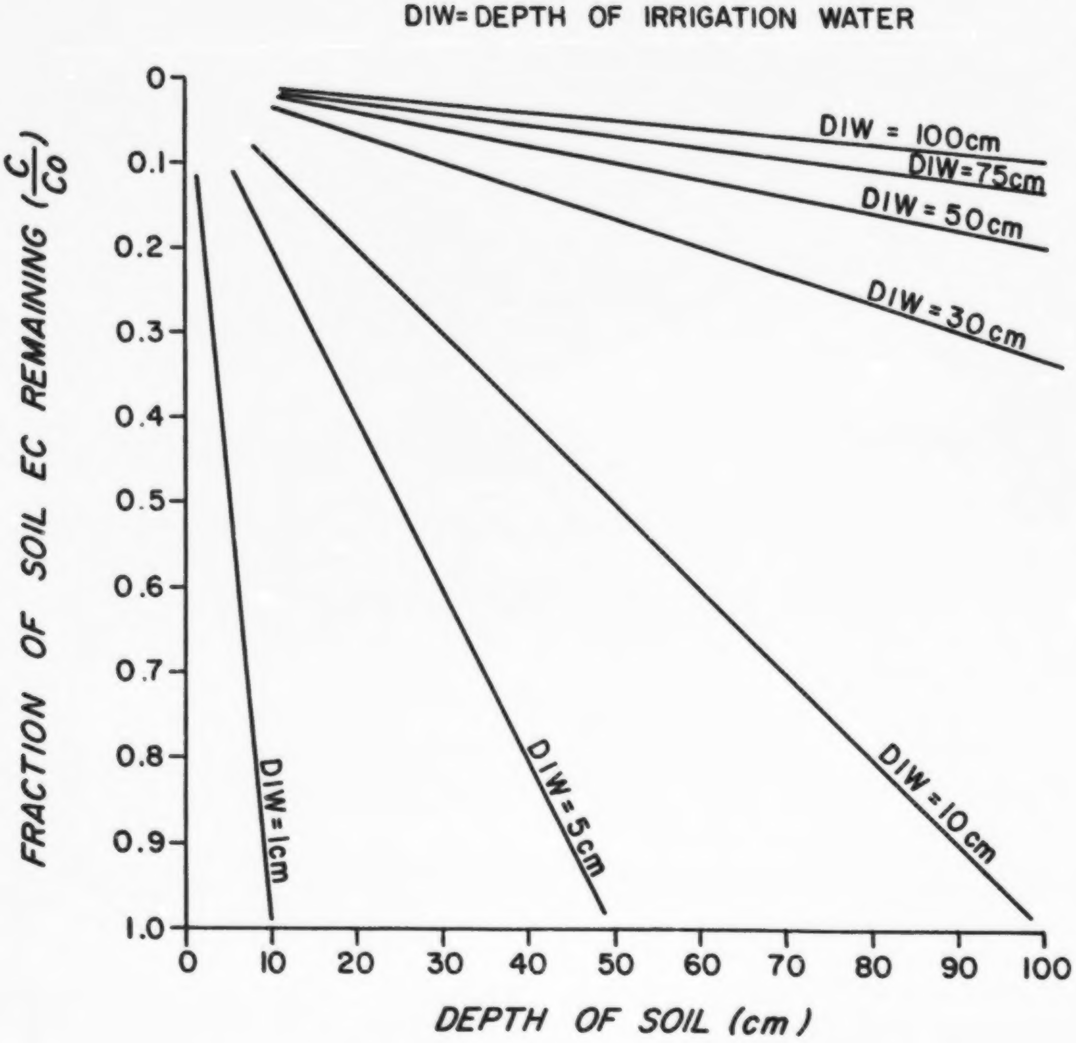


FIGURE 2 HOFFMAN EQUATION RESULTS FOR LEACHING BY INTERMITTENT PONDING

$$\frac{C}{Co} = \left(\frac{DS}{DIW}\right)(0.1)$$

Combining Figure 1 data with Hoffman's equation gives a rule of thumb: for each centimetre of leaching water applied, crop yields will increase 1% on a strongly saline soil.

FACTOR 3

Consumptive Use of Saline Groundwater

The process of capillary rise of saline groundwater and removal of relatively salt-free water by crops with subsequent salt concentration in the root zone can cause rapid salinization. Data from van Schaik and Milne (1963) equate to an average salinity increase of 3.0 mS/cm in one year in the top 0.9 metres of soil cropped to grass over a shallow water table. Graveland (1970) found as much as a 77% salt content increase in the top 15 cm of soil over a 13 day period in July, Alberta's peak consumptive use period. Consumptive use by crops is the major driving force for salinization with cropped areas salinizing far more rapidly than non-cropped in the presence of a saline, relatively constant shallow water table and limited rainfall (Leo, 1963: van Schaik and Milne, 1963; Sandoval and Benz, 1966). This cropping effect on salinization is reasonable since water moves up from the water table as a result of soil-water-potential differences (Stuff and Dale, 1978); a greater potential gradient is maintained by crop transpiration plus evaporation than by evaporation alone. With consumptive use typically greater nearer the soil surface (Raats, 1974), the gradient is upward until countered by rainfall or irrigation.

Thus there are two opposing forces or gradients; the downward leaching of salts by rainfall and irrigation, and the upward movement of salt from the water table. A net downward flow must be maintained for reclamation to occur. Irrigation creates intensive downward gradients of short duration; consumptive use of groundwater creates a slight but nearly continuous upward gradient.

Though subsurface drains are installed, capillary forces are still in effect, carrying dissolved salts upward. Again this emphasizes the need for water applications to leach salts downward and establish a net downward gradient. The depth of the drains, hence the depth of the water table, has a major influence on the amount of consumptive use of groundwater. The following data from Pohjakas and Read (1981) and McMullin and Read (1983) illustrates this:

TABLE 1. Consumptive Use of Groundwater.

	Water Table Depth 1.8 m Groundwater Use		Water Table Depth 1.2 m Groundwater Use	
Soil & Crop	mm/day	% of Total	mm/day	% of Total
LSB*	1.0	19	3.0	49
LSF	0	0	0.9	42
CLB	1.5	29	4.2	44
CLF	0	0	0.7	25

* LS = loamy sand, CL = clay loam, B = cropped to barley, F = left fallow; eg. LSB = loamy sand cropped to barley

Note the high consumptive use of groundwater from the shallower water table.

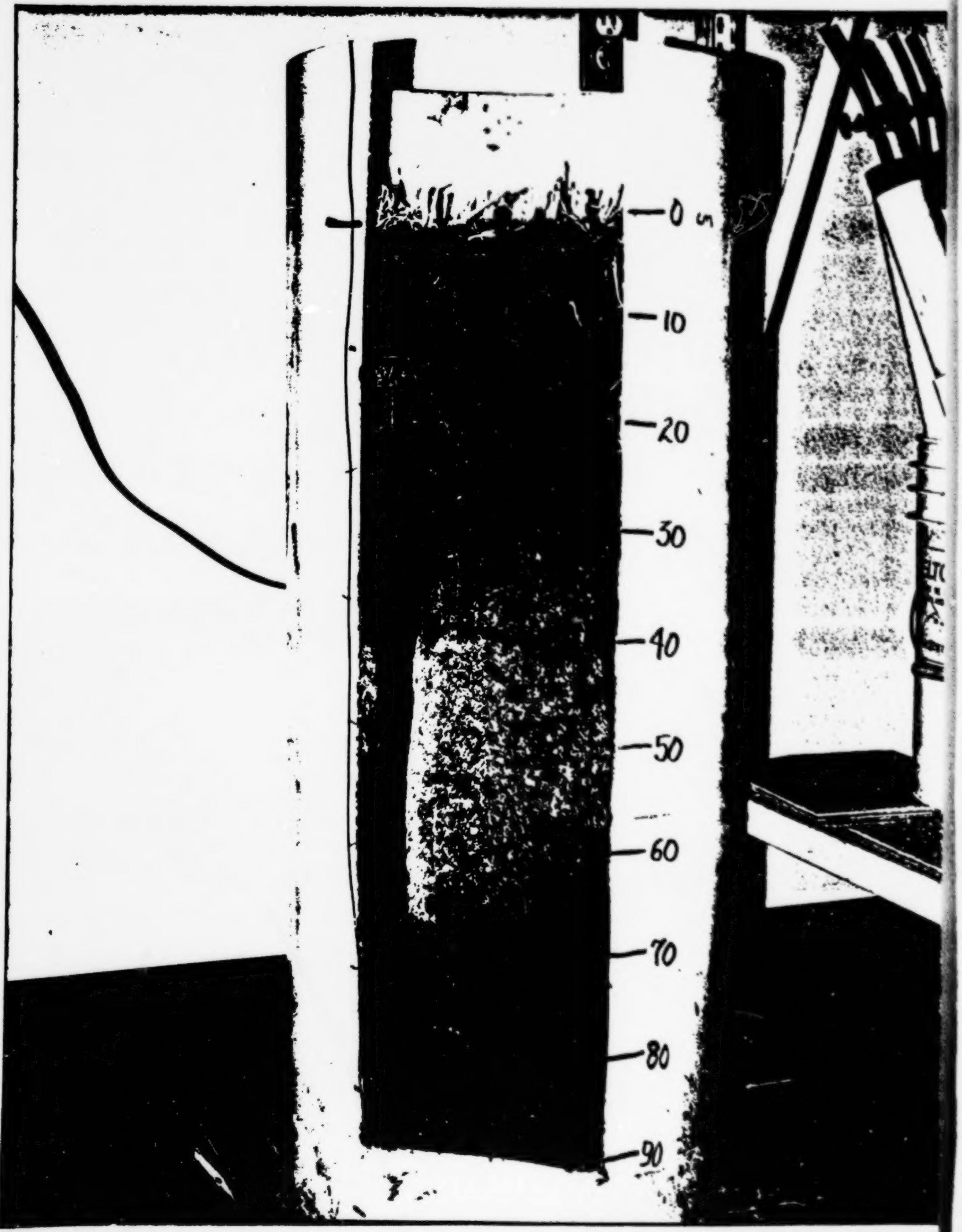
In another experiment near completion (by the author) saline "groundwater" was maintained at a 1 m depth in soil columns cropped to barley. The soil columns were composed of disturbed soil from Ap horizons having very low salinity levels. The EC of the groundwater was 60 mS/cm. Water use of the saline groundwater in the sandy clay loam columns averaged 82% of the 4.6 mm/day crop water use measured in a distilled water check; the crop in a silty clay loam soil used 5.8 mm/day, 96% of a distilled water check. The accompanying photo of one of the columns shows the high salt accumulation above the 1.0 m water table depth that developed as a result. Water use averaged only 30% that of the distilled water checks the following year.

Again, consumptive use of saline groundwater will increase with shallower depth to the water table and in concert with capillary rise, can bring significant amounts of salt into the root zone. Where leaching water can be applied, subsurface drains may be installed at shallower depths and a net downward salt movement can be maintained. Where rainfall only is available, subsurface drains must be deeper to reduce capillary rise and permit net downward movement induced by natural precipitation.

FACTOR 4

Salt Load Buffering in a Sulfate Dominated Soil System

Hoffman's equation for reclamation planning was developed on chloride dominated soils. McMullin (1983) showed this equation under-estimated the amount of leaching water required to reclaim a saline soil with sulphate as the dominant anion. This under-estimation was attributed to dissolution of sulphate and carbonate salts that existed as precipitates in the soil. Figures 3a and 3b show the results of this experiment on a specific ion basis.


0 cm
10
20
30
40
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60
70
80
90

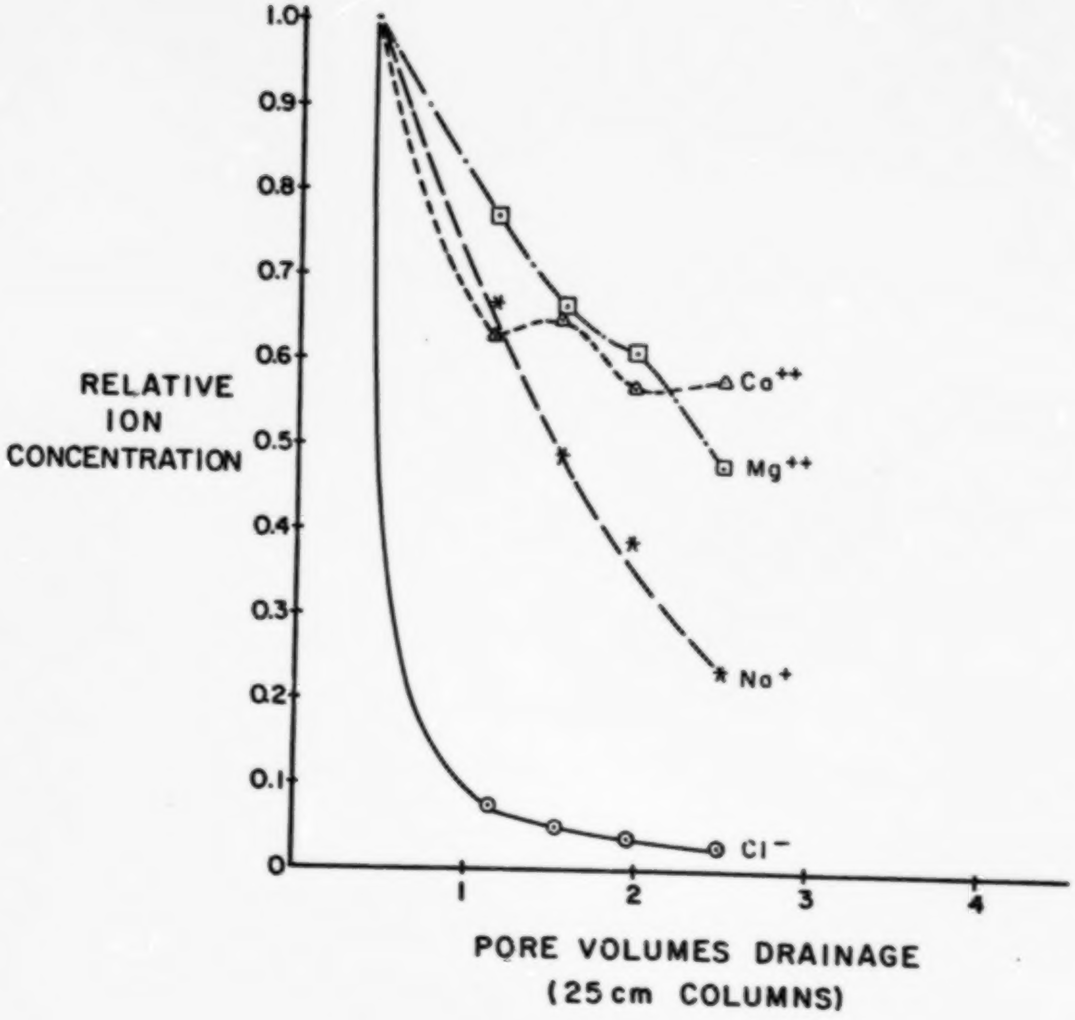

FIGURE 3a. - SPECIFIC ION CONCENTRATIONS IN EFFLUENT WITH ACCUMULATED DRAINAGE VOLUME.

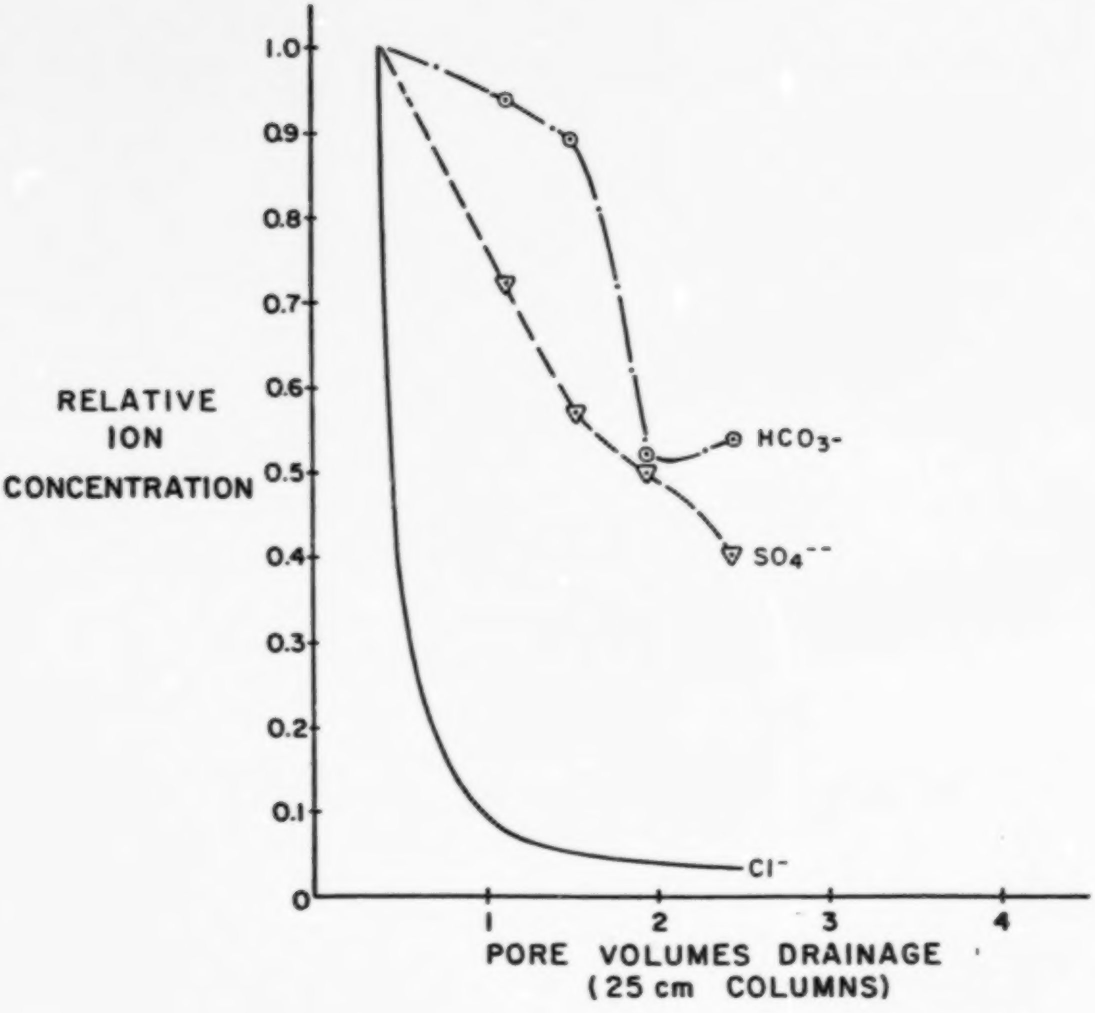

FIGURE 3b. - MAJOR ANION CONCENTRATIONS WITH ACCUMULATED DRAINAGE VOLUME.

The chloride ion is easily leached with no reserve to continually supply the leaching solution. The sulfate and bicarbonate anion concentration's are maintained in the drainage effluent in much higher proportions.

The key characteristic controlling these contrasting anion systems is the solubility of salts of the anions as given in Table 2. (Weast, 1974). Solubilities are given at the indicated temperatures because these values are documented; the relative solubilities do not change much at lower temperatures.

Table 2. Solubilities of Selected Calcium, Magnesium and Sodium Salts.

COMPOUND	SOLUBILITY (g/100cc water)	WATER TEMP. °C
$CaCl_2$	159	100
$CaSO_4.2H_2O$	0.222	100
$CaCO_3$	0.0018	75
$MgCl_2$	72.7	100
$MgSO_4$	73.8	100
$MgCO_3$	0.0106	?
NaCl	39.1	100
Na_2SO_4	42.7	100
Na_2CO_3	45.5	100

The greatest differences in solubilities are the sulfate and carbonate salts of calcium and the carbonate salt of magnesium when compared to their chloride counterparts. This in practical terms means that calcium sulfates and carbonates and magnesium sulfates will precipitate out of solution to form crystalline salts in soils quite readily when relatively small quantities of these ions exist in the soil. These crystalline salts then remain in the soil to buffer the soil solution near the solubility limits of the salts until the crystalline material is all removed. As calcium is released to solution, cation exchange can occur, releasing more sodium to solution (Evangelou et.al., 1984). Leaching rates will be slower in these buffered soils, requiring more water to pass through the soil to complete the reclamation process. The highly soluble chlorides would rarely, if ever, precipitate out to buffer soil solutions.

Using a serial dilution technique McMullin and Karkanis (1983) determined similar results showing that a calcium sulfate buffer existed in this soil. Other ions were also buffered to a lesser extent as shown in Figures 4a and 4b. The difference between the "measured" and the "calculated" curve for a given "dilution" was used as a measure of the amount of buffer. The 1:40 extract removed approximately 3 times the salt that the saturated extract removed. There was no buffering of the chloride ion.

In practical terms this means more leaching water must be applied to leach out salts in Alberta soils than would be estimated by equations based on chloride systems.

CONCLUSIONS

1) Adequate water to meet consumptive use, plus provide a leaching fraction must be applied or reclamation of saline soils with shallow subsurface drains will not occur. The tendency in Alberta is to provide less water than consumptively used.

2) As a rule of thumb, barley yields on strongly saline land will increase 1% for each centimetre of leaching water applied.

3) The upward gradient of salt-bearing capillary water must be countered with leaching water. Where less leaching water is available subsurface drains must be installed at deeper depths to reduce capillary transport of salts into the root zone.

4) The solution salt load of sulfate dominated soils may be buffered by precipitated salts, thus requiring a greater volume of leaching water than comparable chloride dominated soils to bring about comparable reclamation.

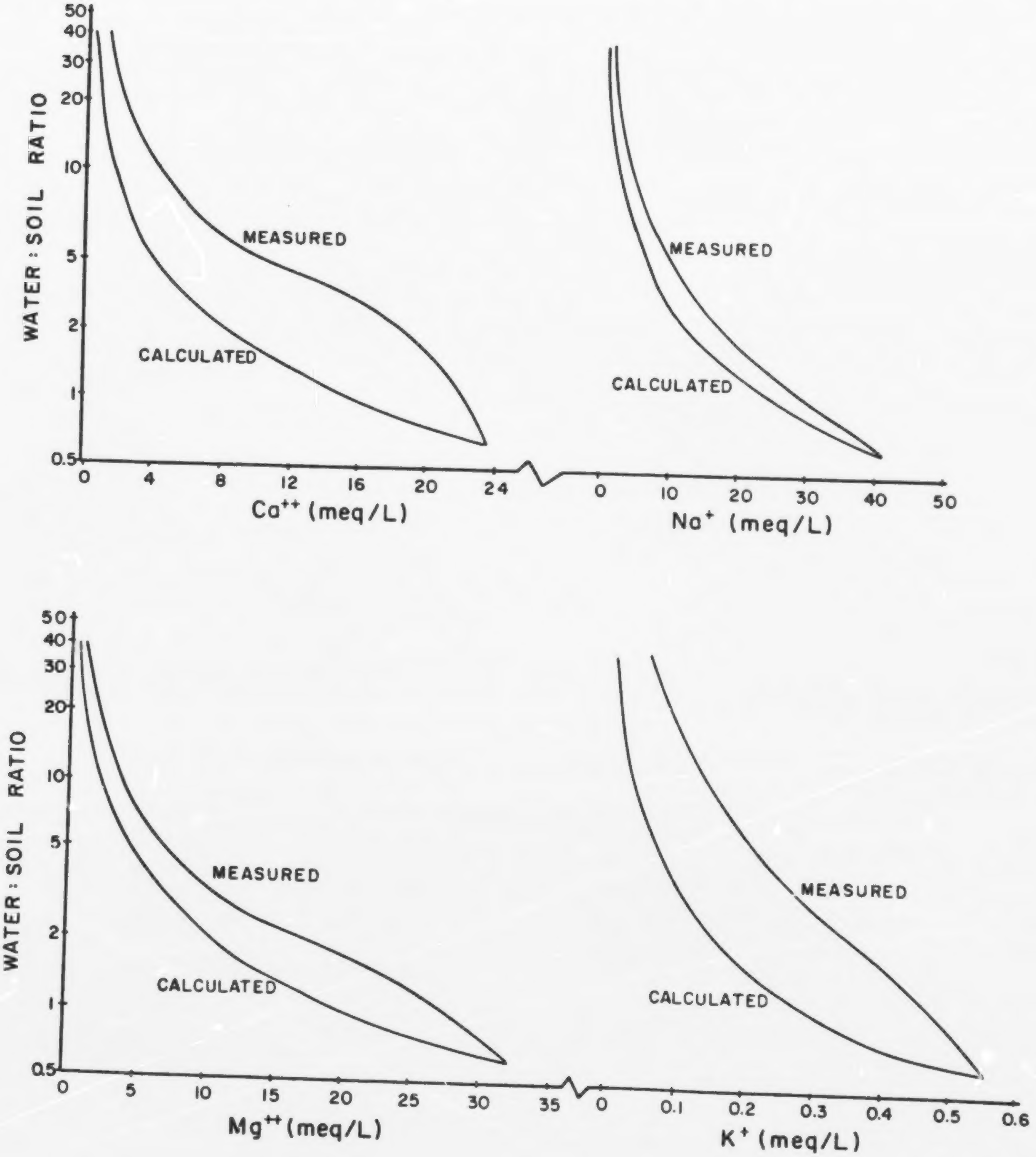

FIGURE 4a. - CALCULATED AND MEASURED DILUTION CURVES FOR MAJOR CATIONS.

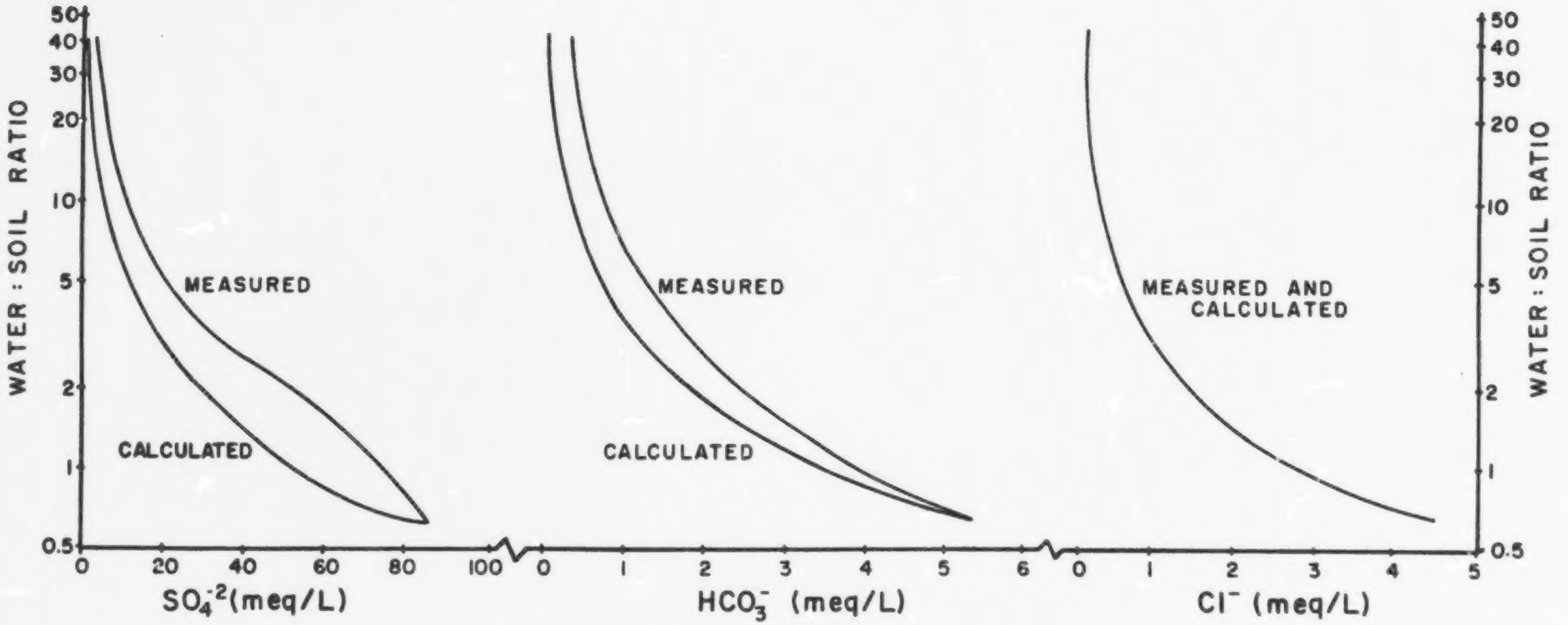

FIGURE 4b - CALCULATED AND MEASURED DILUTION CURVES FOR MAJOR ANIONS.

REFERENCES CITED

ARAR, A., DOORENBOS, J., and THOMAS, R. G., 1970. Irrigation and drainage in relation to salinity and waterlogging. FAO/UNDP(TA) Seminar on Methods of Amelioration of Saline and Waterlogged Soils, Baghdad, Iraq.

EVANGELOU, V. P., WHITTIG, L. D., and TANJI, K.K., 1984. Dissolved mineral salts derived from Mancos shale. J. Environ Qual. 13:146-150.

GRAVELAND, D. N., 1970. Migration of soluble salts in an irrigated field in relation to rainfall and irrigation. Can. J. Soil Sci. Vol. 50: 43-45.

HARKER, D. B., 1984. Summary Report, Soil Salinity Research Workshop. Irrigation and Conservation Division, Alberta Agriculture, Lethbridge, Alberta.

HOFFMAN, G. J., 1980. Irrigation management - salinity control. Proc. ASAE 2nd National Irrigation Symposium, Irrigation Challenges of the 80's. University of Nebraska, Lincoln, NE., pp. 166-174.

LEO, M.W.M., 1963. Effects of cropping and fallowing on soil salinization. Soil Sci. 96: 422-427.

McMULLIN, R. W., 1983. Evaluation of several leaching equations. Research and Resource Development Sector, Applied Research Report. Alberta Agriculture, Lethbridge, Alberta, pp. 270-284.

McMULLIN, R. W., and KARKANIS, P., 1983. Determining the amount of leachable salt in a saline soil. Research and Resource Development Sector, Applied Research Report. Alberta Agriculture, Lethbridge, Alberta. pp. 285-297.

McMULLIN, R.W., and READ, W. J., 1983. Groundwater contribution to consumptive use. Research and Resource Development Sector. Applied Research Report. Alberta Agriculture, Lethbridge, Alberta. pp. 182-188.

POHJAKAS, K., and KEARNS, K. J., 1980. Evaluation of center pivot irrigation practises in southern Alberta. pp. 59-71. Annual Applied Research Report. Irrigation Division, Alberta Agriculture. Lethbridge, Alberta.

POHJAKAS, k., and READ, W.J., 1981. Controlled water table experiment with barley and summerfallow. pp. 160-167. Annual Applied Research Report. Irrigation Division, Alberta Agriculture. Lethbridge, Alberta.

RAATS, P.A.C., 1974. Steady flows of water and salt in uniform soil profiles with plant roots. Soil Sci. Soc. Am. Proc. 38: 717-722.

SANDOVAL, Fred M., and BENZ, L.C., 1966. Effect of bare fallow, barley and grass on salinity of a soil over a saline water table. Soil Sci. Soc. Amer. Proc. 30: 392-396.

STUFF, R.G., and DALE, R.F., 1978. A soil moisture budget model accounting for shallow water table influences. Soil Sci. Soc. Am. J. 42: 637-643.

van SCHAIK, J. C., and MILNE, R.A., 1963. Salt accumulation in a glacial till soil in the presence of saline groundwater at shallow depths. Can. J. Soil Sci. 43: 135-140.

van SCHILFGAARDE, J., BERNSTEIN, L., RHOADES, J.D., and RAWLINS, S.L., 1974. Irrigation management for salt control. J. Irr. and Drain Div. ASCE, Vol. 100, No. IR3. pp. 321-338.

WEAST, R. C., (ed) 1974. Handbook of Chemistry and Physics. CRC Press. Cleveland, Ohio.

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